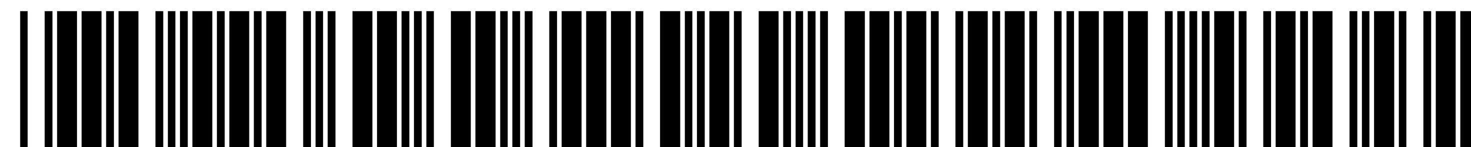

US007550813B2

(12) **United States Patent**
**Suzuki**

(10) **Patent No.: US 7,550,813 B2**
(45) **Date of Patent: Jun. 23, 2009**

(54) **PHOTOELECTRIC CONVERTING FILM STACK TYPE SOLID-STATE IMAGE PICKUP DEVICE, AND METHOD OF PRODUCING THE SAME**

(75) Inventor: **Nobuo Suzuki**, Miyagi (JP)

(73) Assignee: **FujifilmCorporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 382 days.

(21) Appl. No.: **11/133,381**

(22) Filed: **May 20, 2005**

(65) **Prior Publication Data**

US 2005/0263839 A1 Dec. 1, 2005

(30) **Foreign Application Priority Data**

May 28, 2004 (JP) .......................... P.2004-158831

(51) **Int. Cl.**
***H01L 31/18*** (2006.01)

(52) **U.S. Cl.** ....................... **257/440**; 257/414; 257/290; 257/291

(58) **Field of Classification Search** ................. 257/414, 257/440, 290, 291, E31.078
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,820,915 A 4/1989 Hamakawa et al. ........... 257/53
6,930,336 B1 8/2005 Merrill ....................... 257/292

FOREIGN PATENT DOCUMENTS

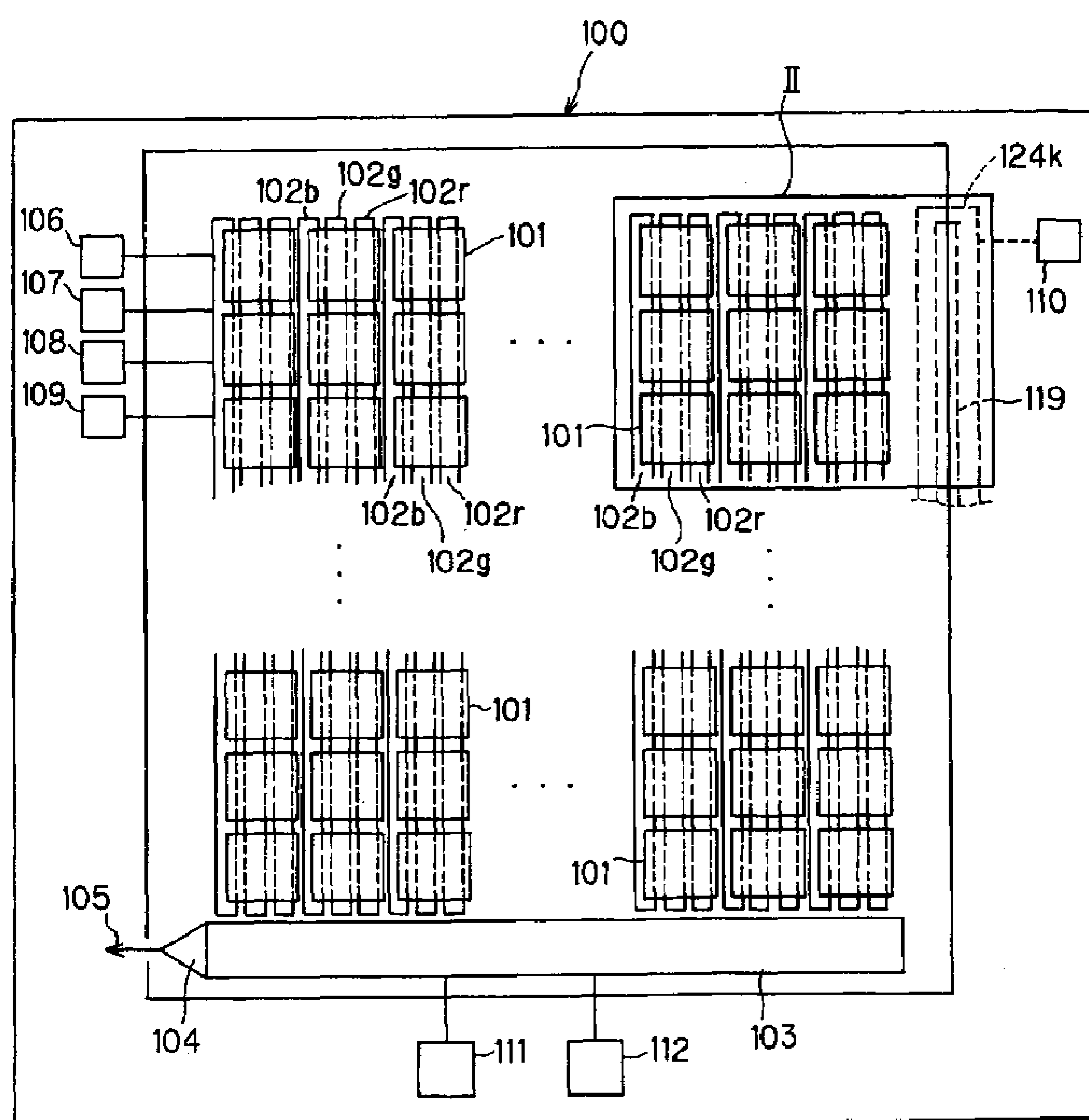
| | | | |
|---|---|---|---|
| JP | 58-103165 | A | 6/1983 |
| JP | 2002-502120 | A | 1/2002 |
| JP | 2002-83946 | A | 3/2002 |
| JP | 2002-083946 | A | 3/2002 |
| JP | 2003-502847 | A | 1/2003 |
| JP | 3405099 | B2 | 3/2003 |
| JP | 2004-335626 | | 11/2004 |

*Primary Examiner*—Eugene Lee
(74) *Attorney, Agent, or Firm*—Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

A solid-state image pickup device comprises: a plurality of photoelectric converting films stacked via an insulating layer, the photoelectric converting films being above a semiconductor substrate in which a signal read circuit is formed, in which each of the photoelectric converting films is sandwiched between a pixel electrode film and an opposing electrode film, wherein the pixel electrode film of an upper one of the photoelectric converting films is connected to the signal read circuit by a longitudinal line passing through a lower one of the photoelectric converting films, and, in the longitudinal line, a passing portion which passes through the lower photoelectric converting film is formed by filling an opening with a conductive material, the opening being formed from a same plane of the pixel electrode film stacked on the lower photoelectric converting film to an upper end face of the insulating layer stacked above the photoelectric converting film.

**7 Claims, 11 Drawing Sheets**



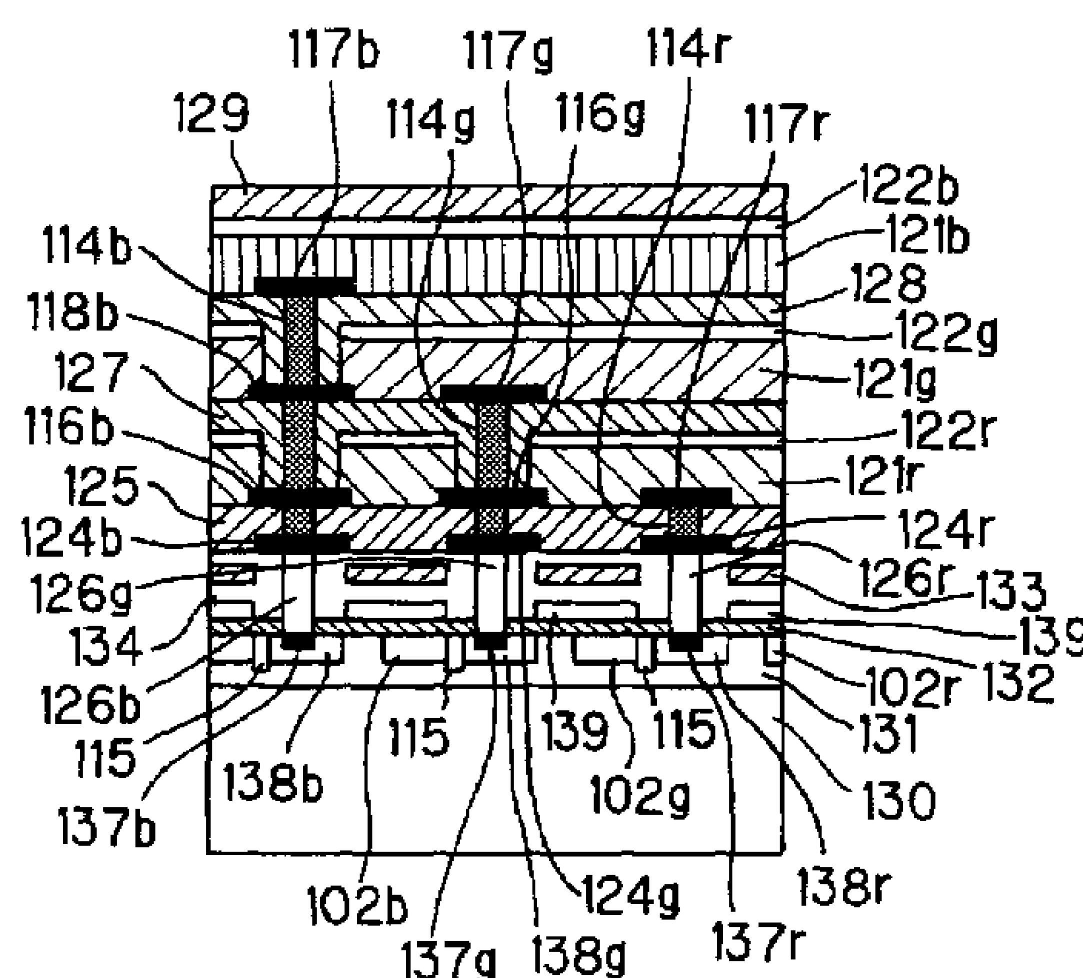



*FIG. 1*

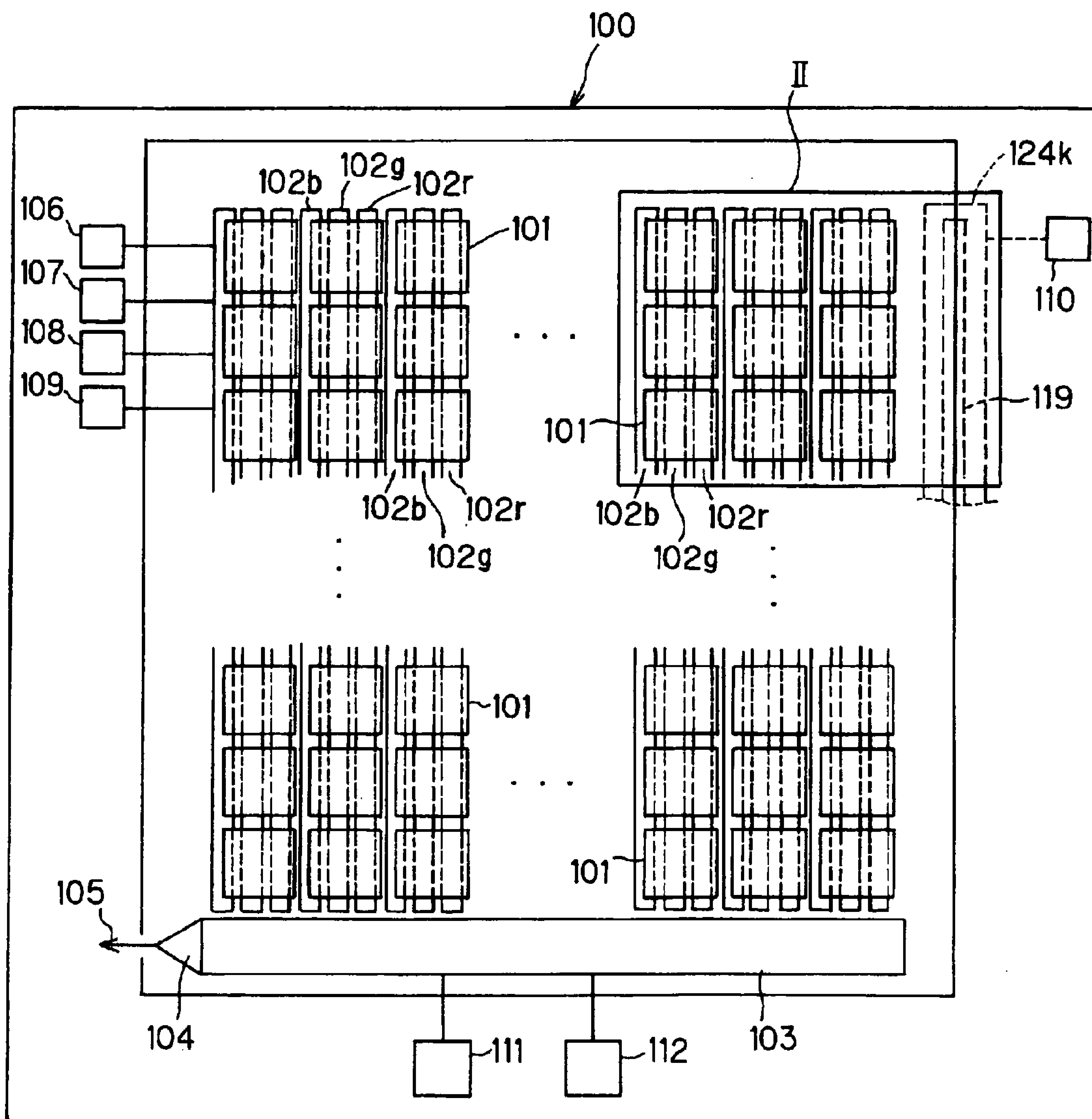


FIG. 2A

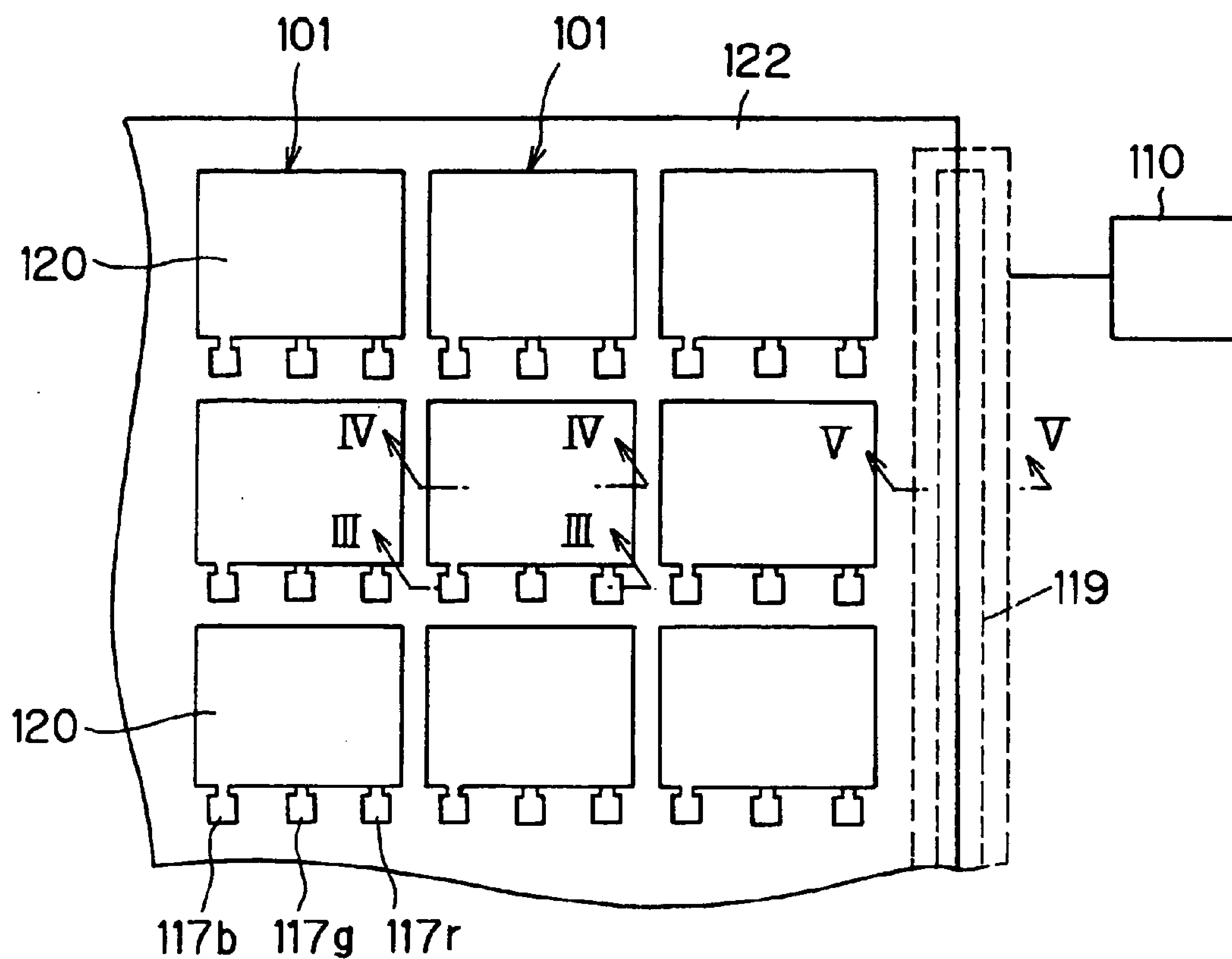



FIG. 2B

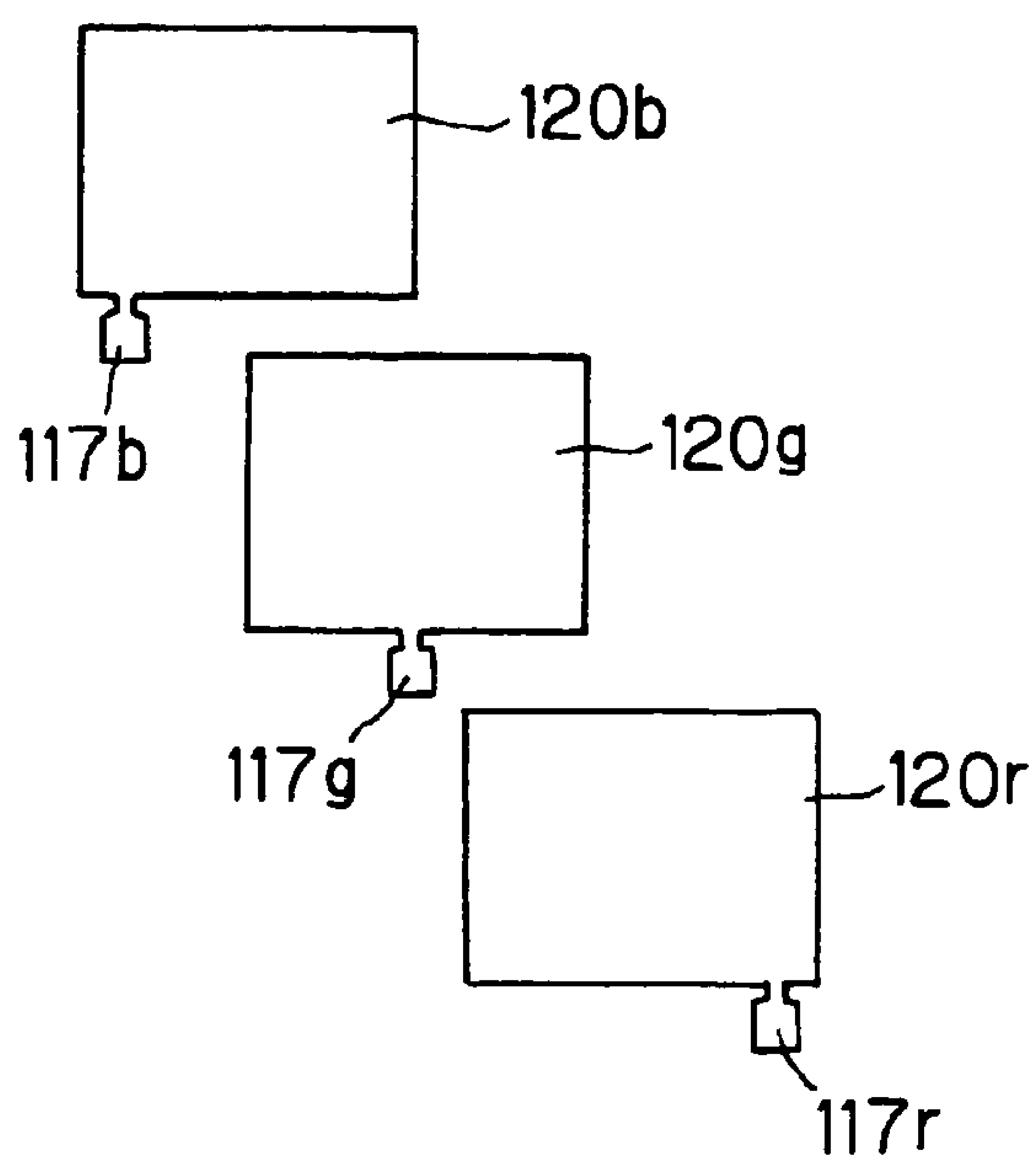


FIG. 3

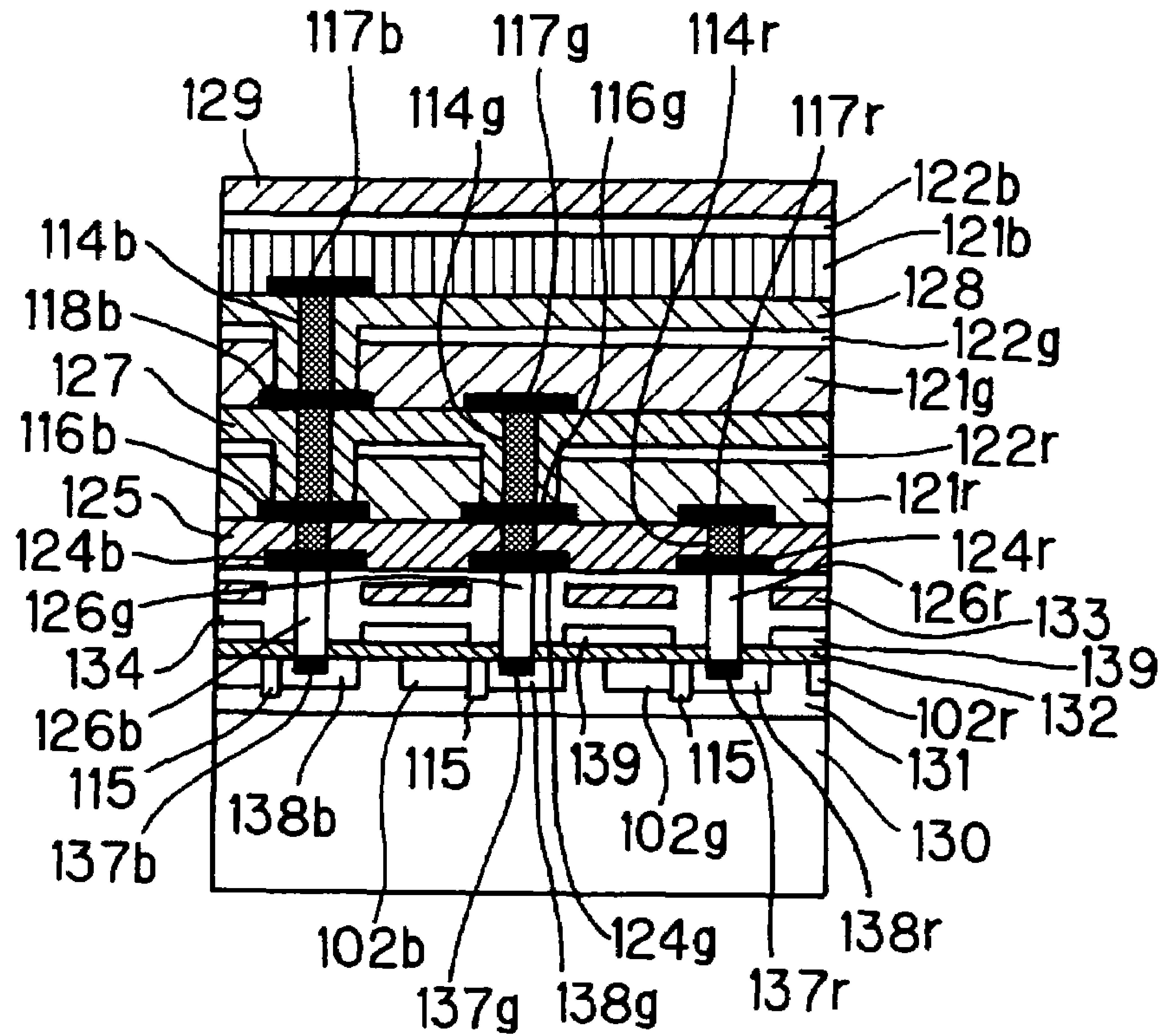



FIG. 4

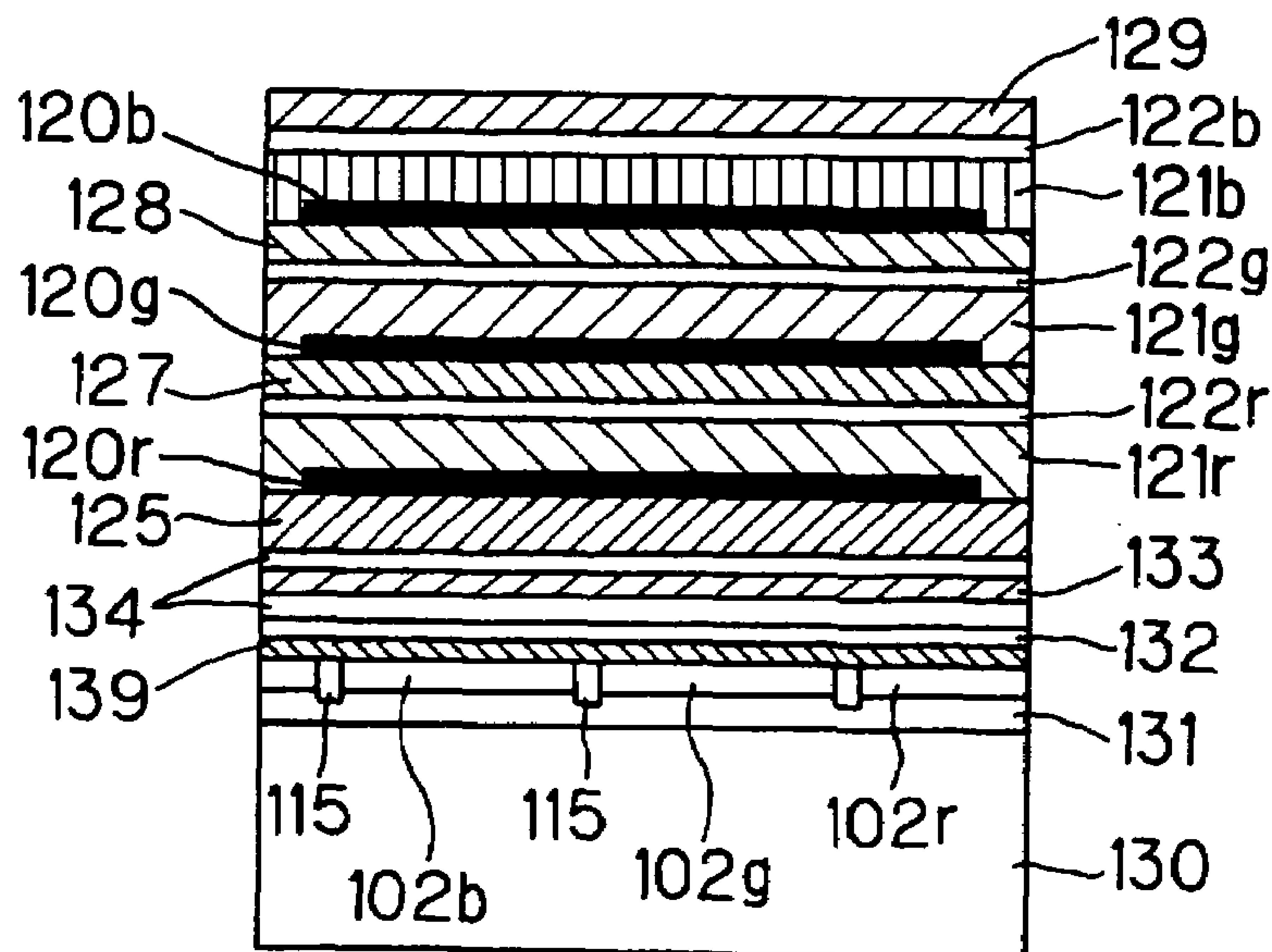


*FIG. 5*

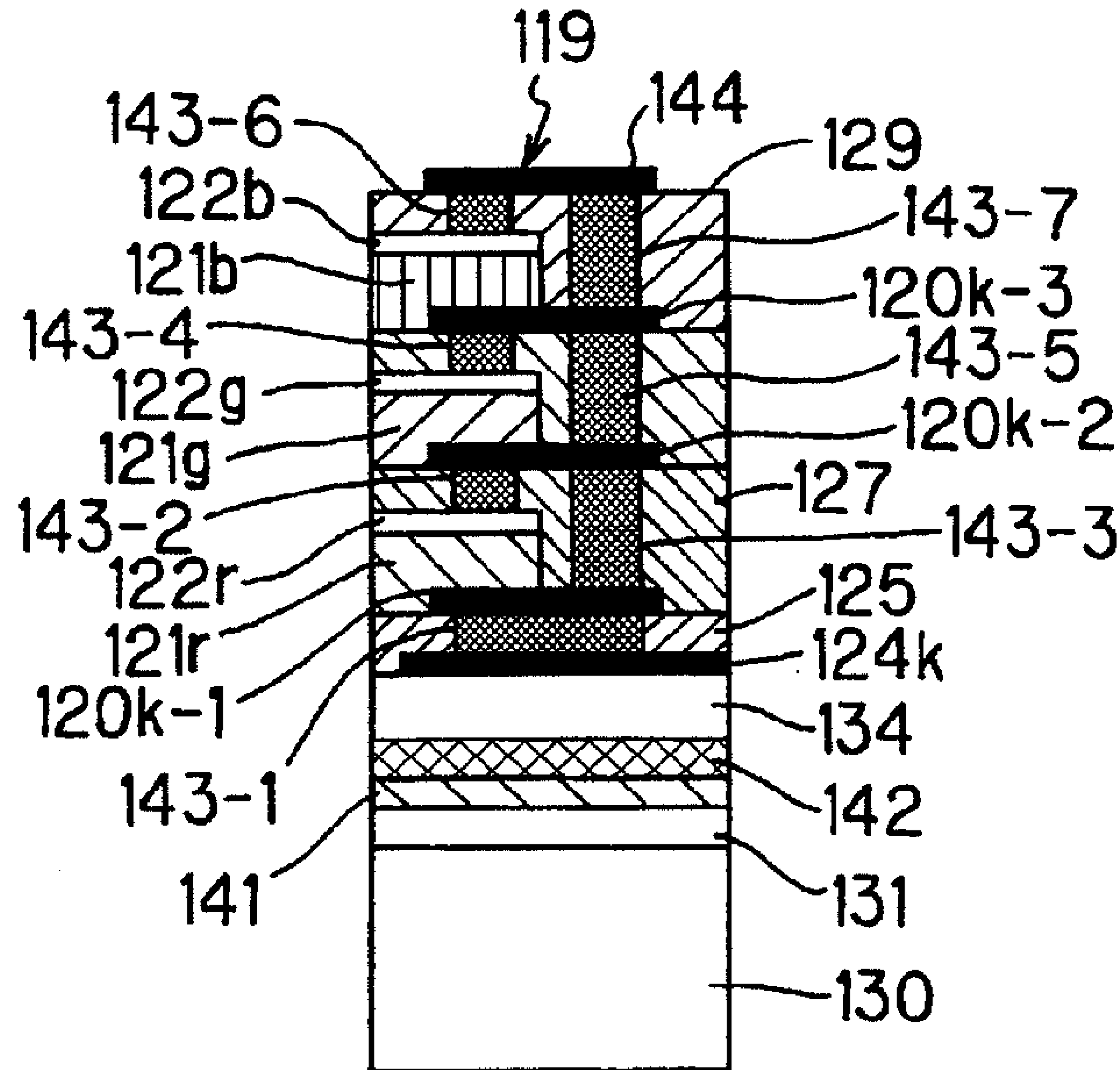



*FIG. 6A*

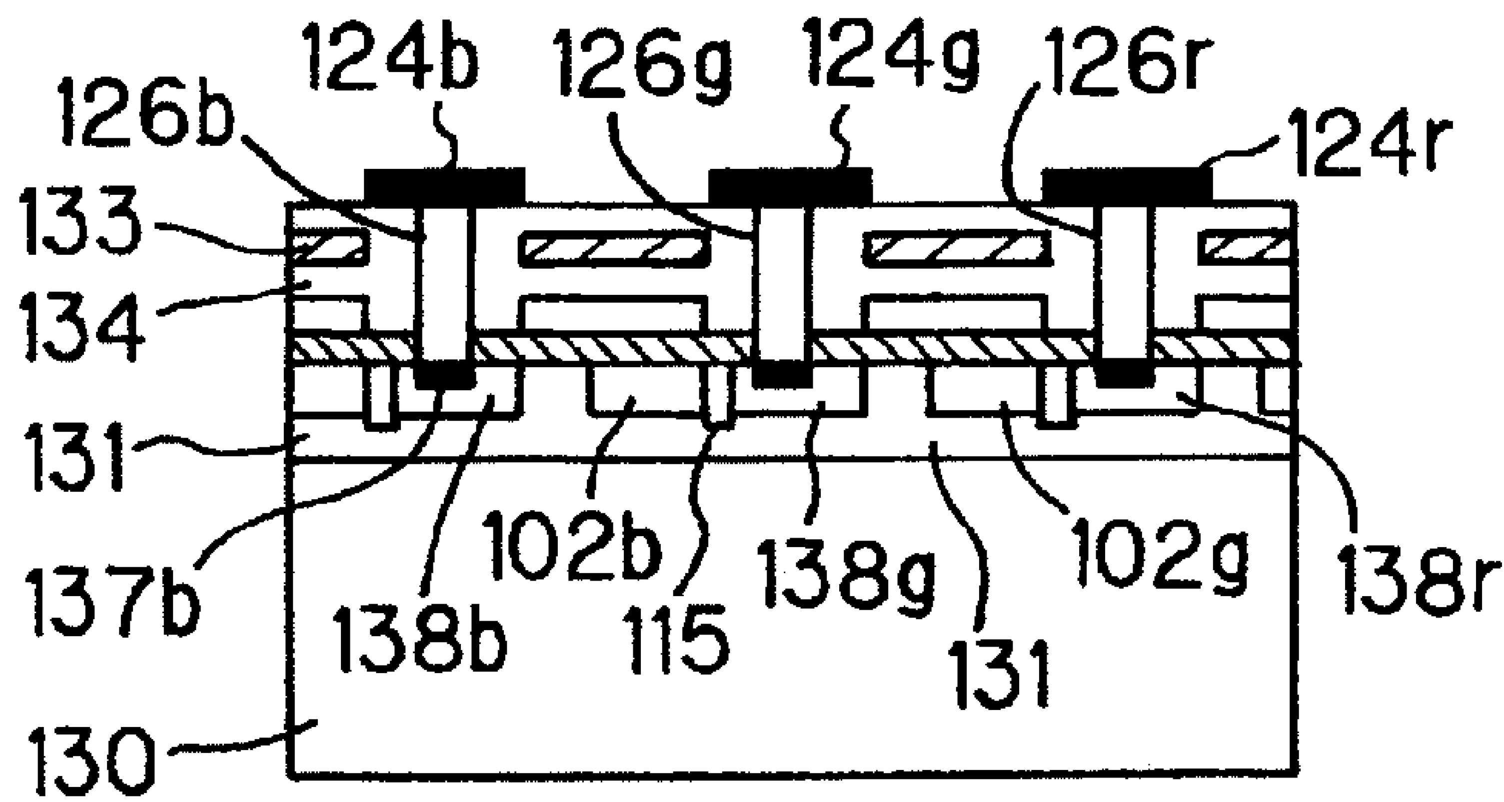



**FIG. 6B**

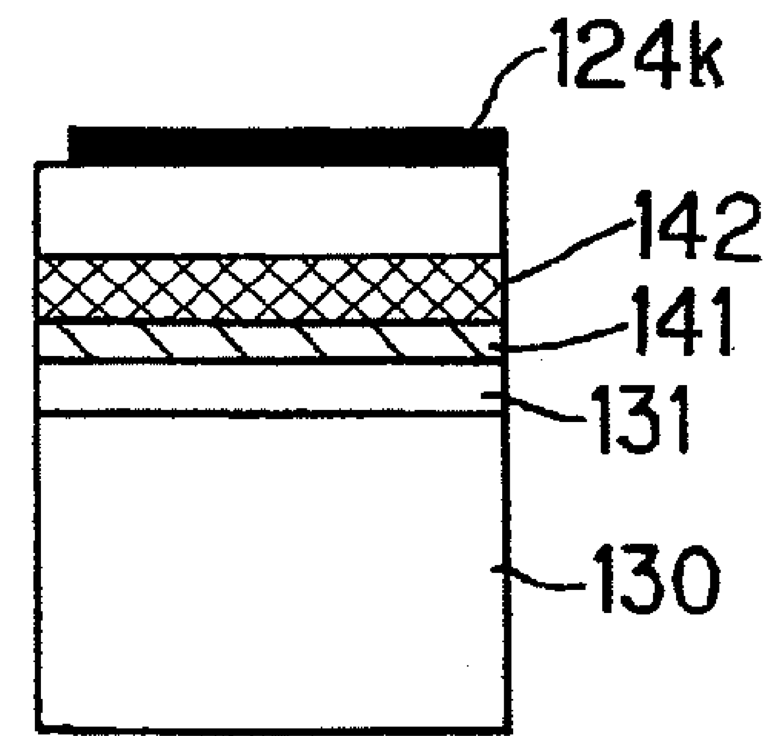



*FIG. 7A*

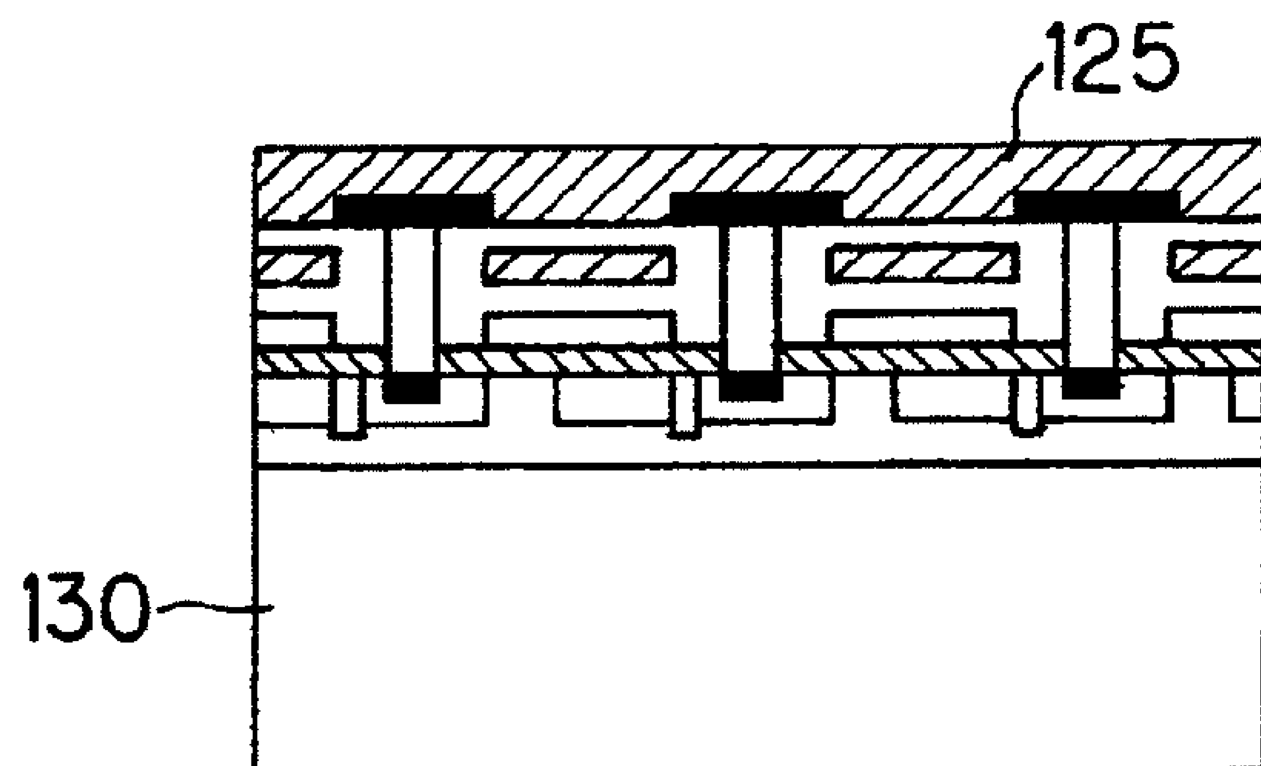



**FIG. 7B**

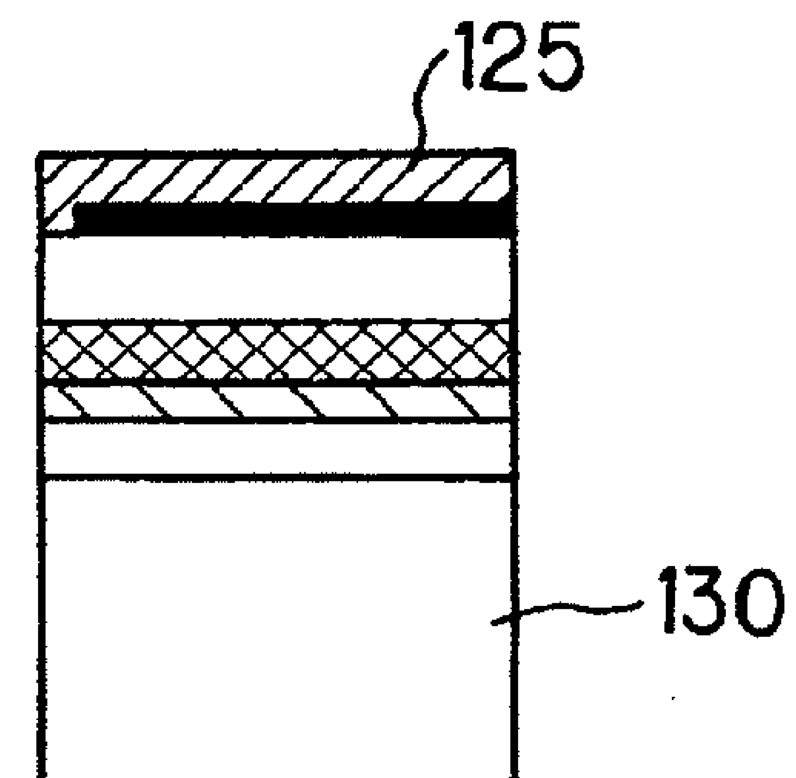


FIG. 8A

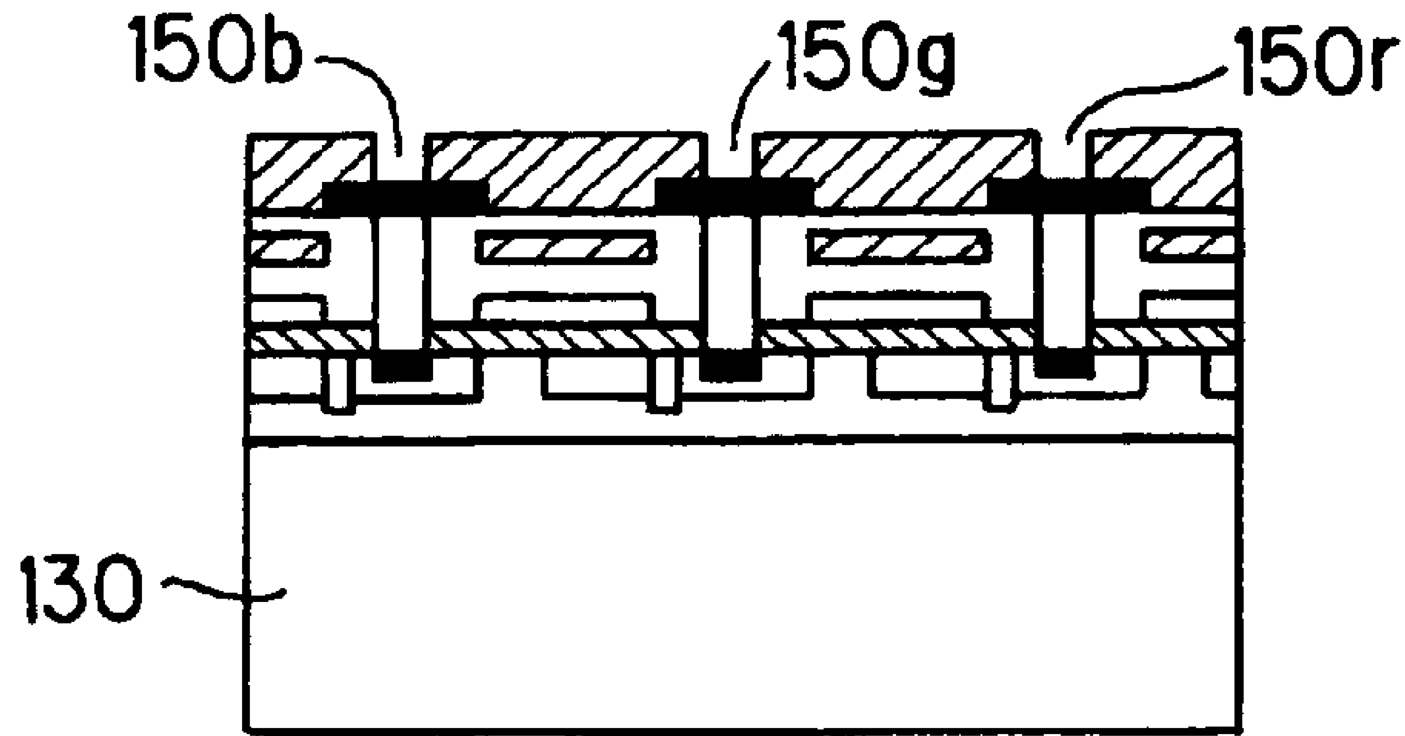



FIG. 8B

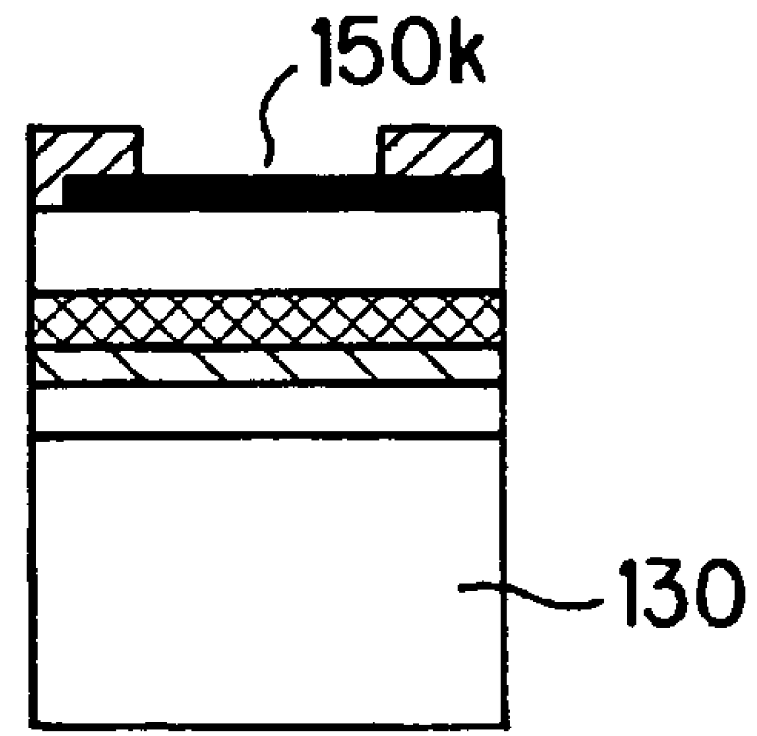



FIG. 9A

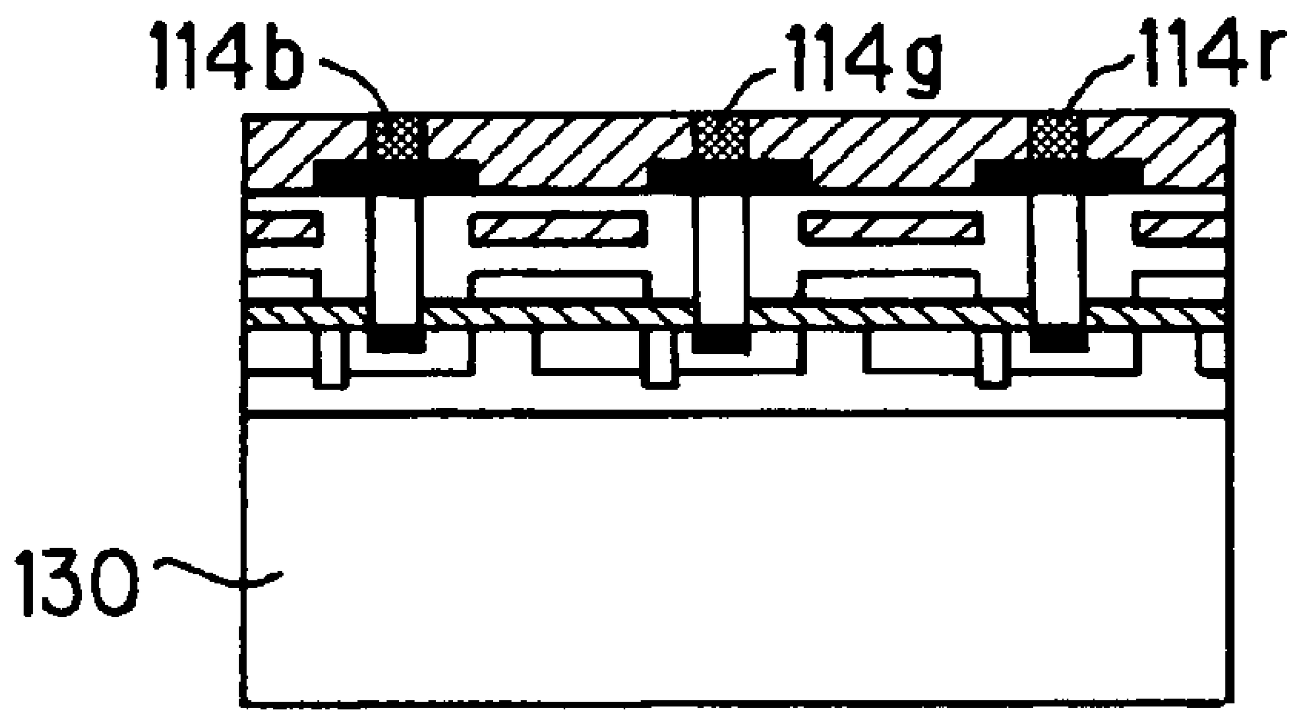



FIG. 9B

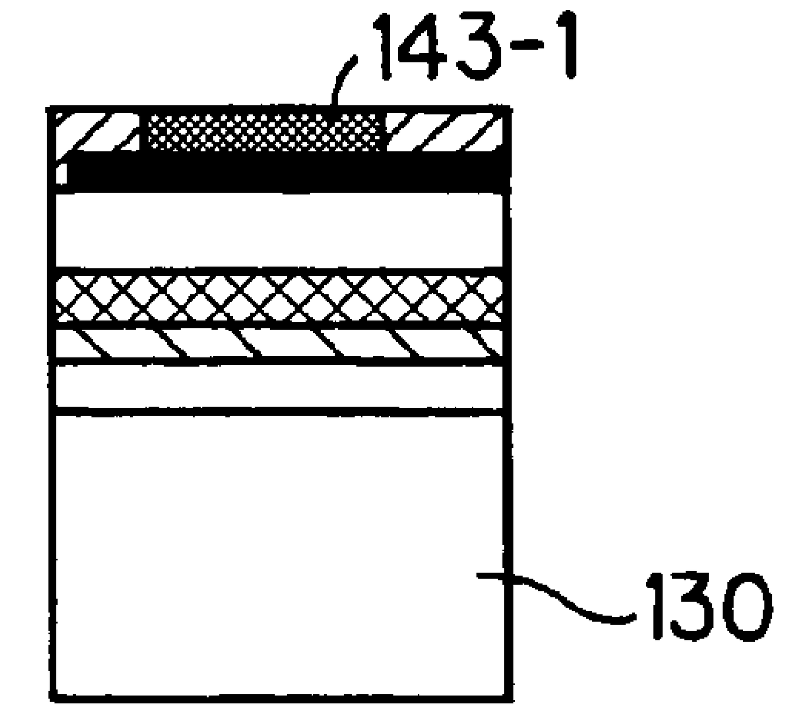



FIG. 10A

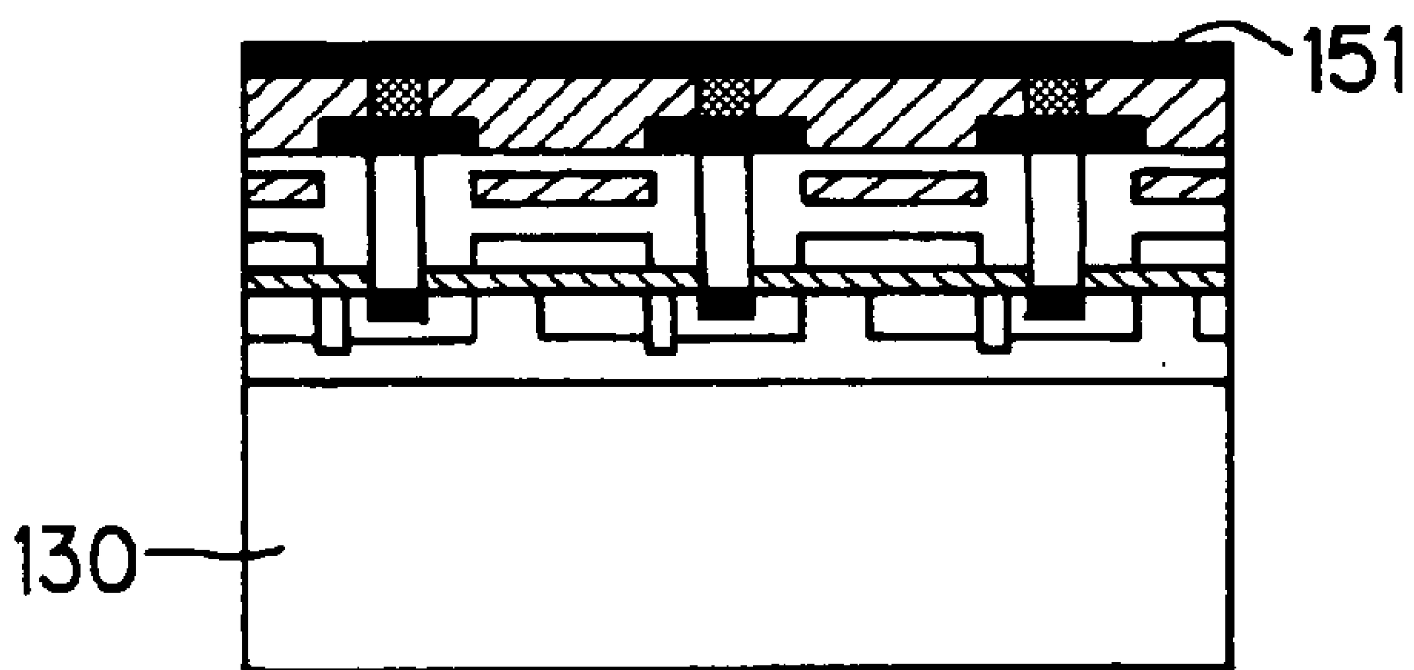



FIG. 10B

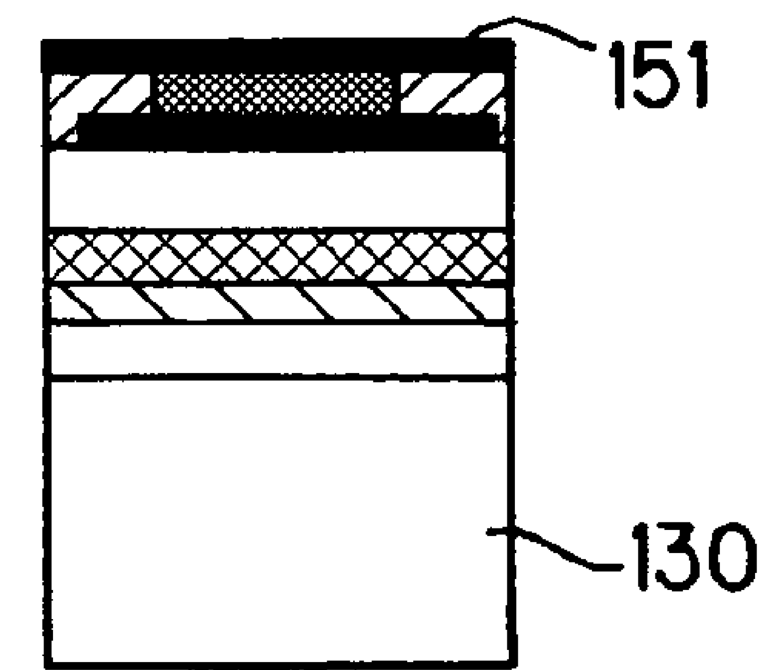



FIG. 11A

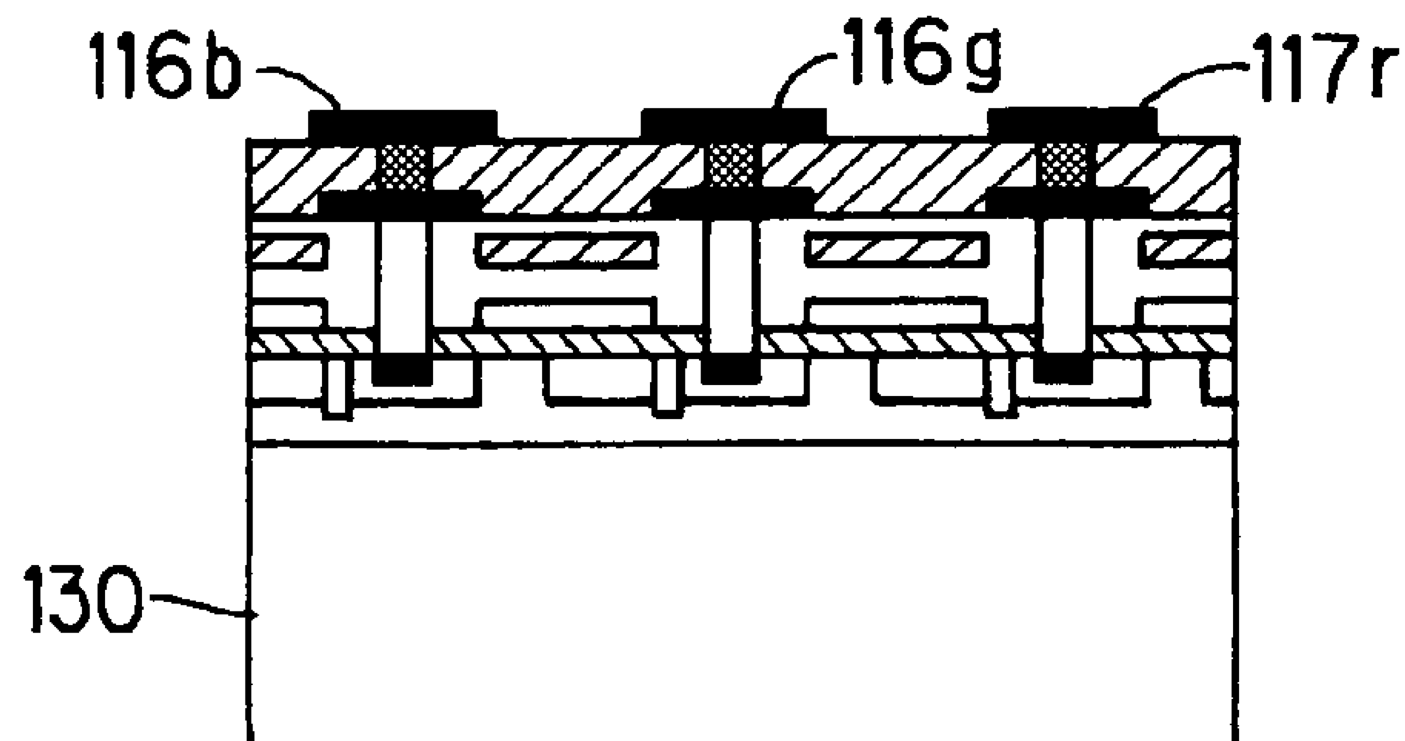



FIG. 11B

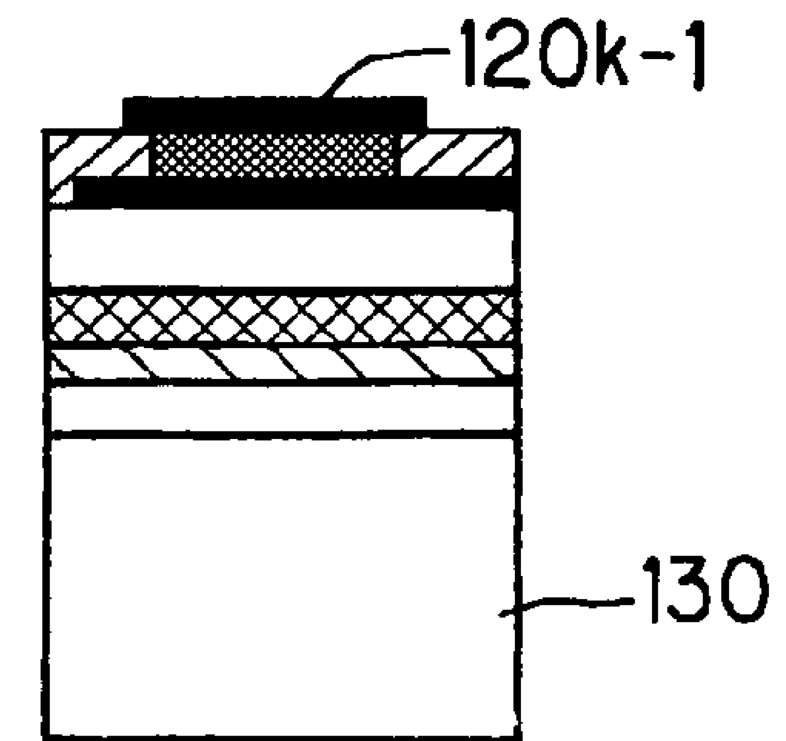


FIG. 12A

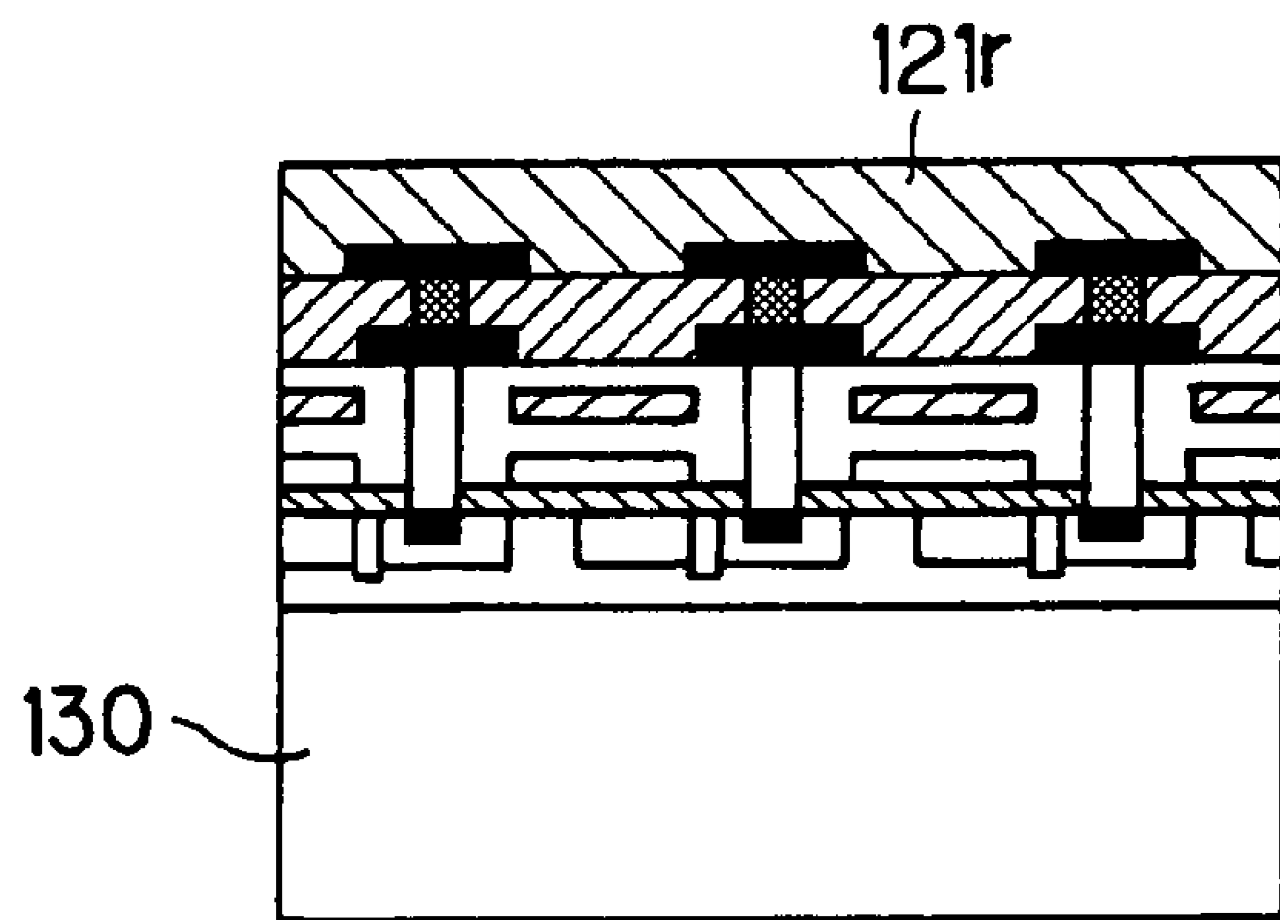



FIG. 12B

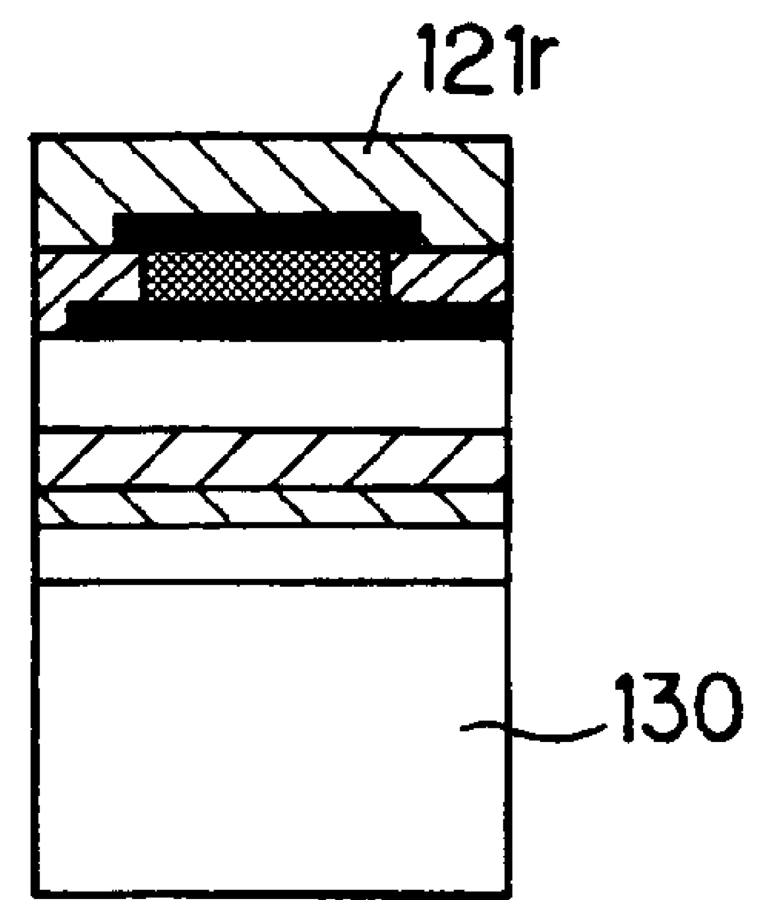



FIG. 13A

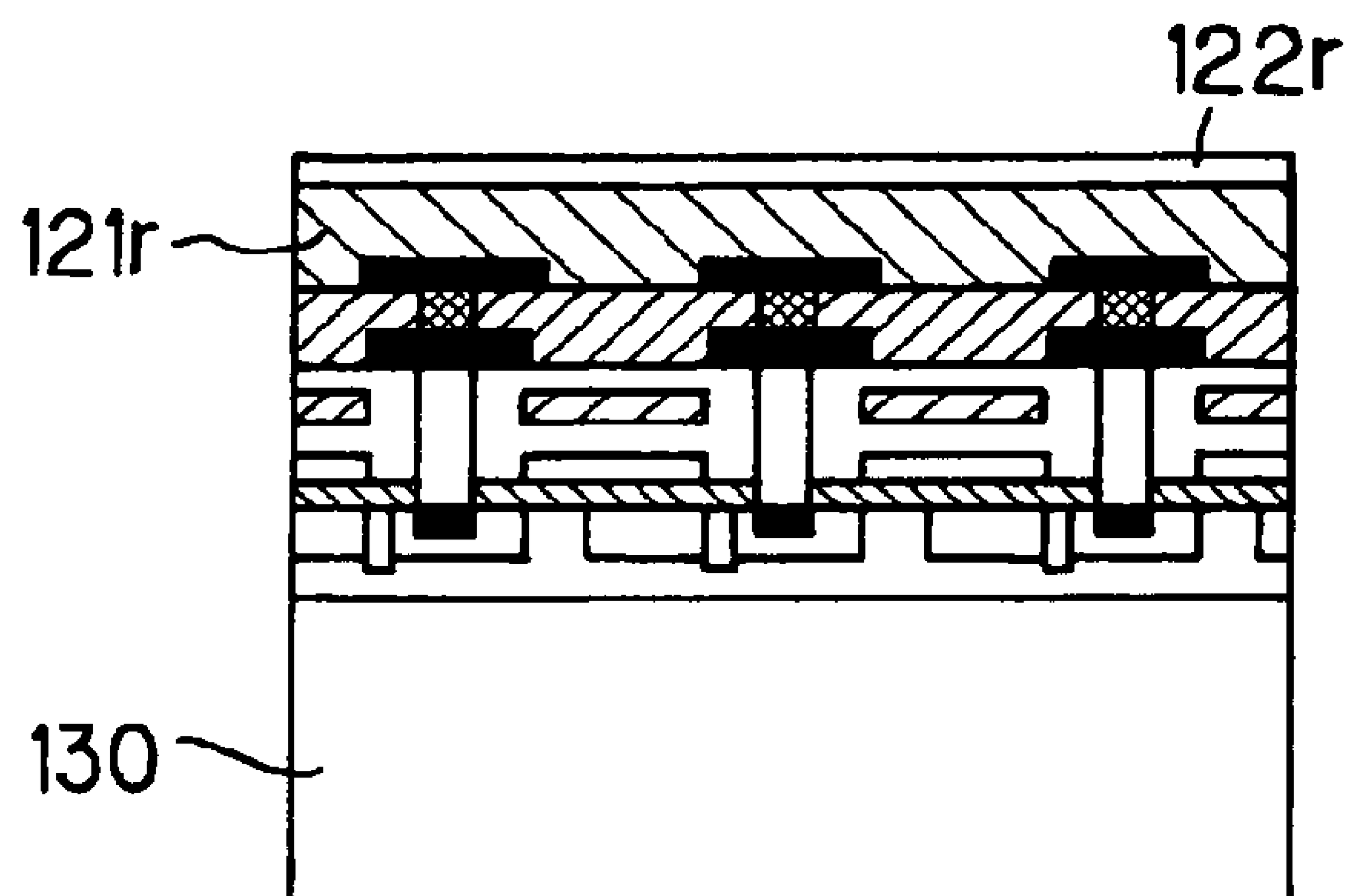



FIG. 13B

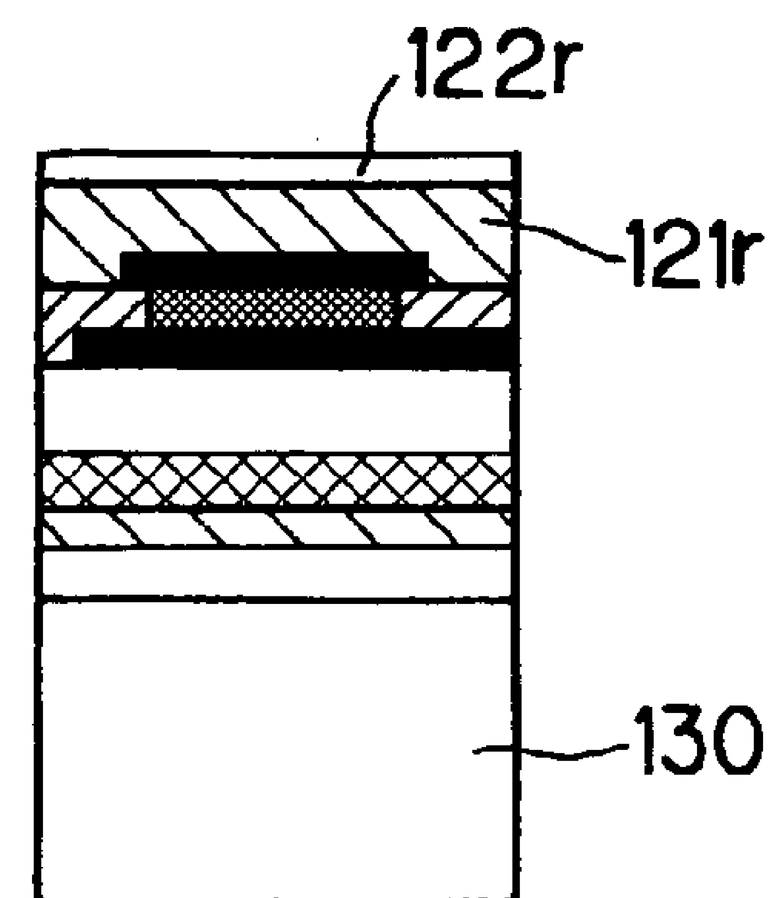



FIG. 14A

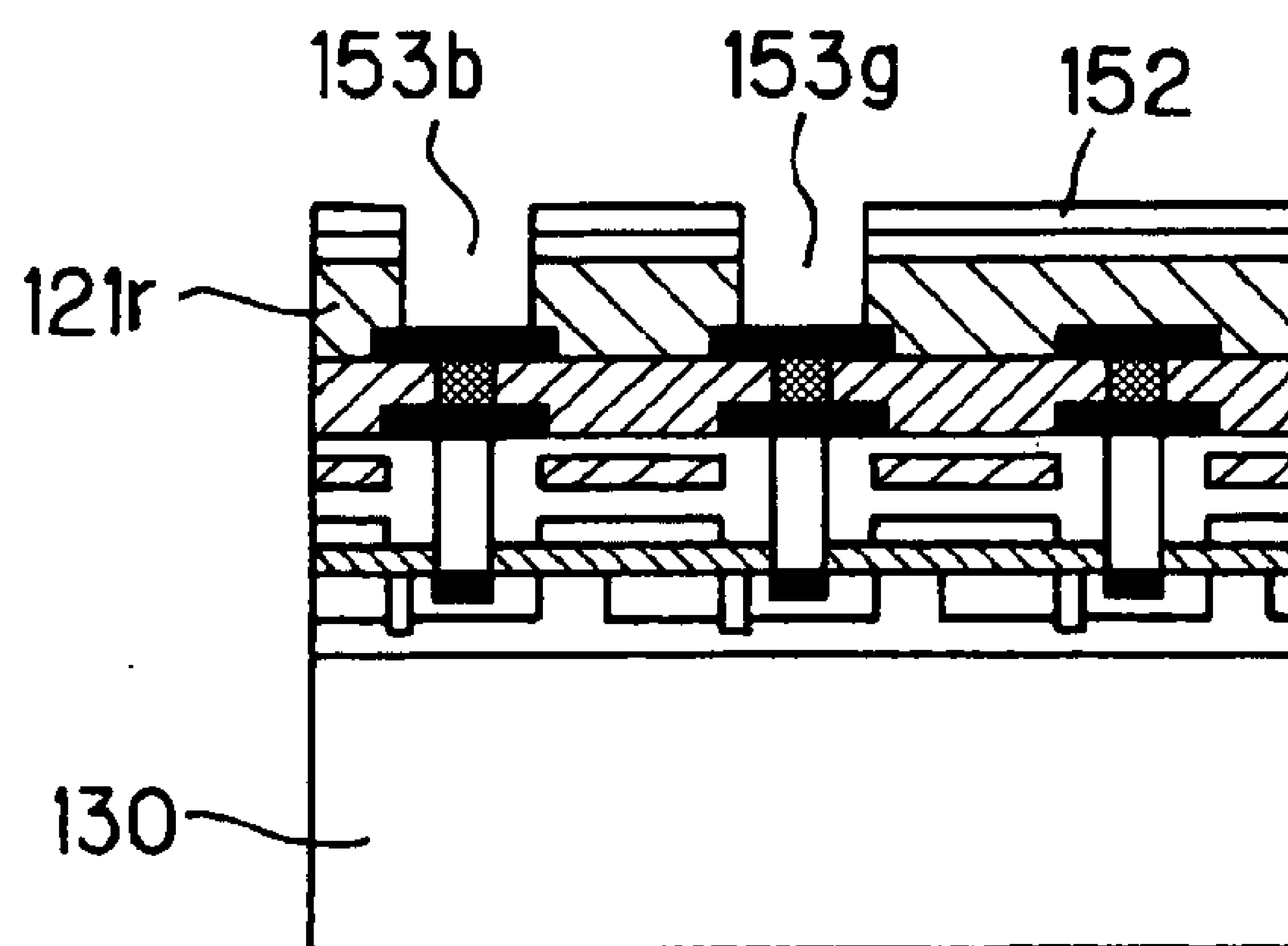



FIG. 14B

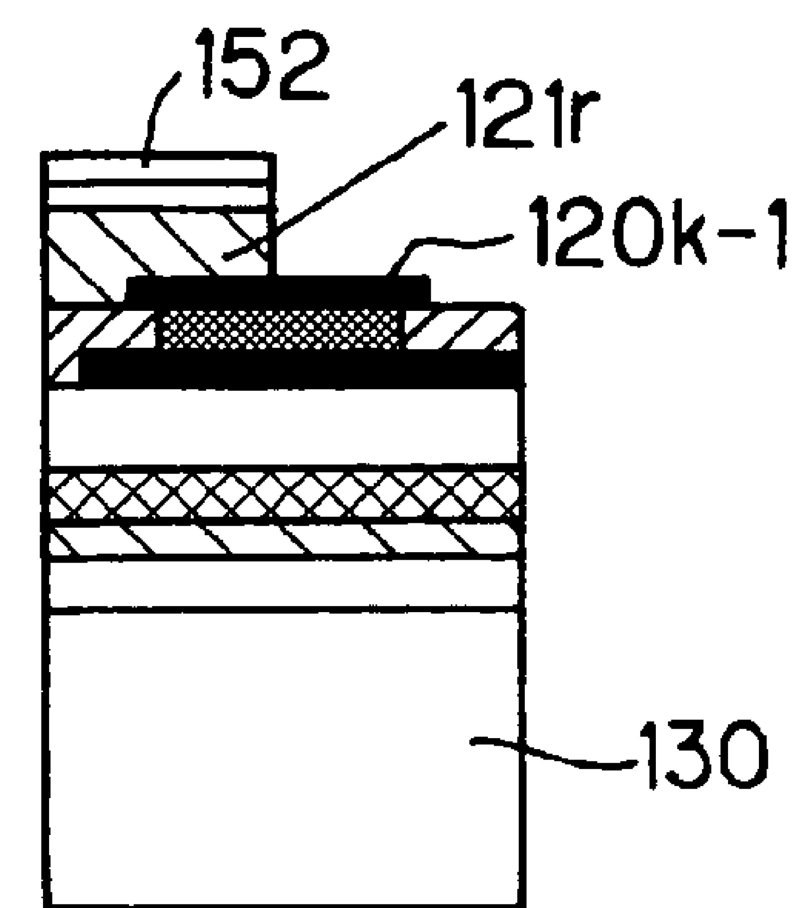


FIG. 15A

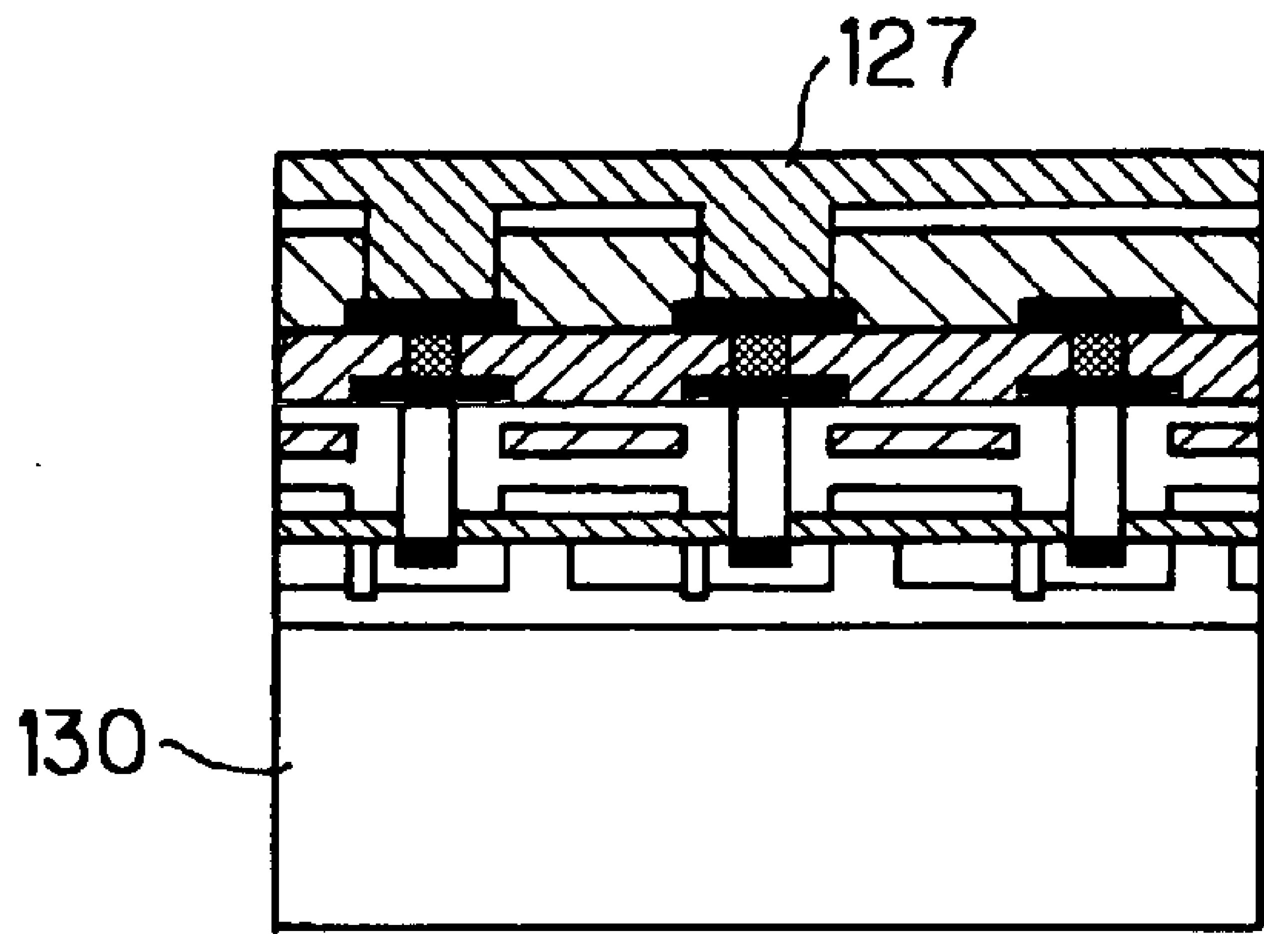



FIG. 15B

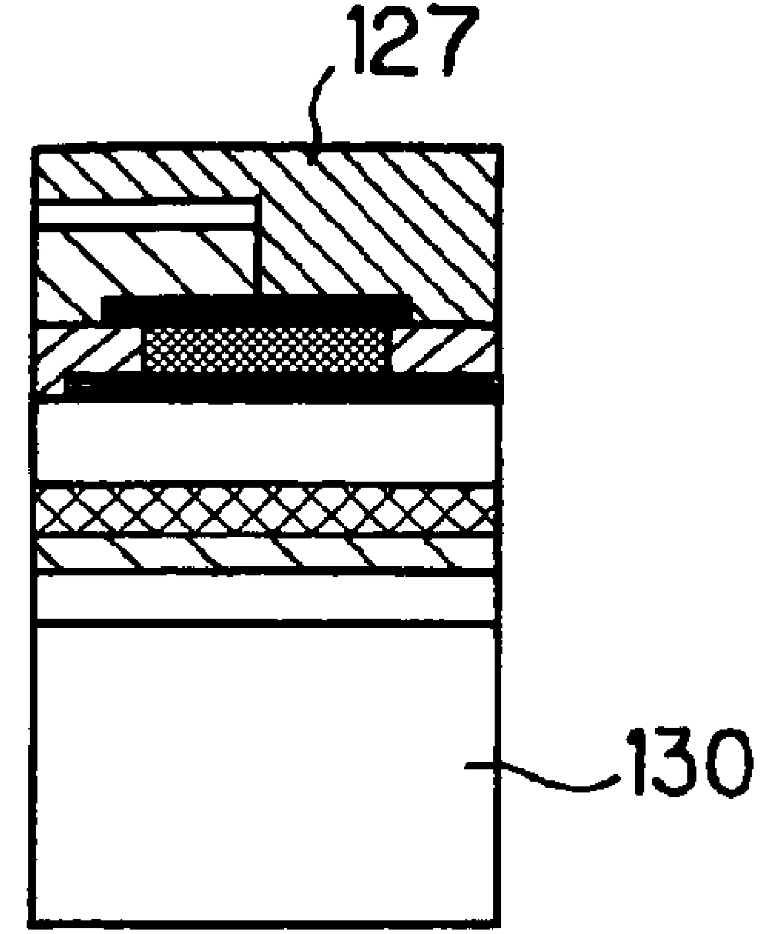



FIG. 16A

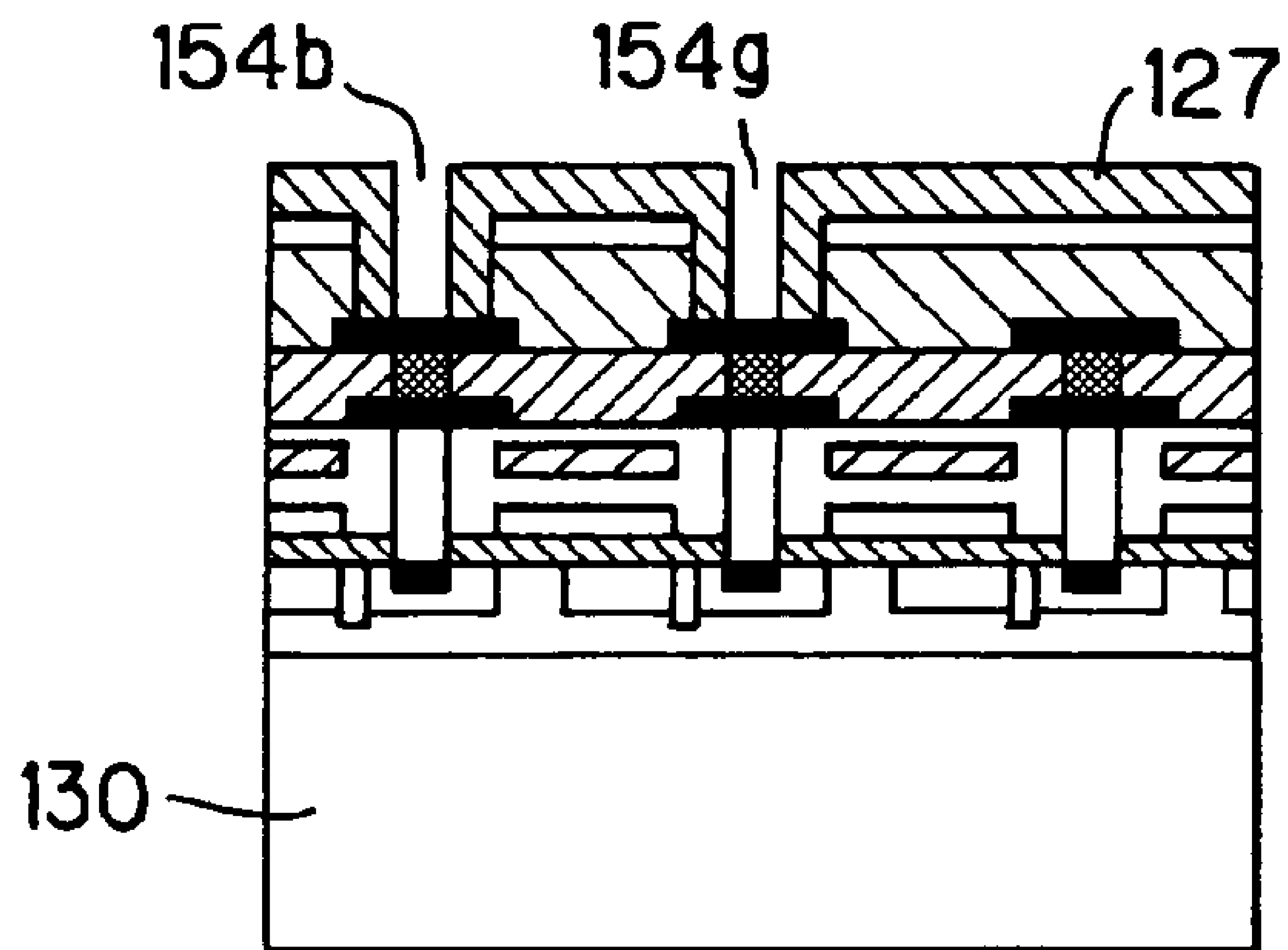



FIG. 16B

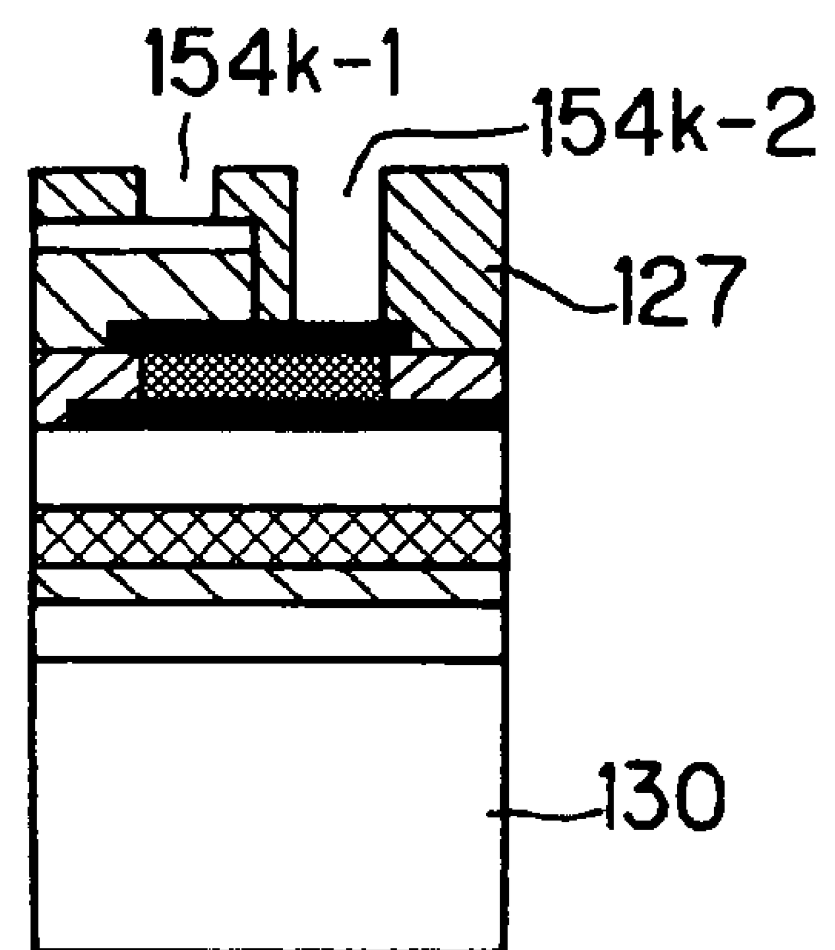



FIG. 17A

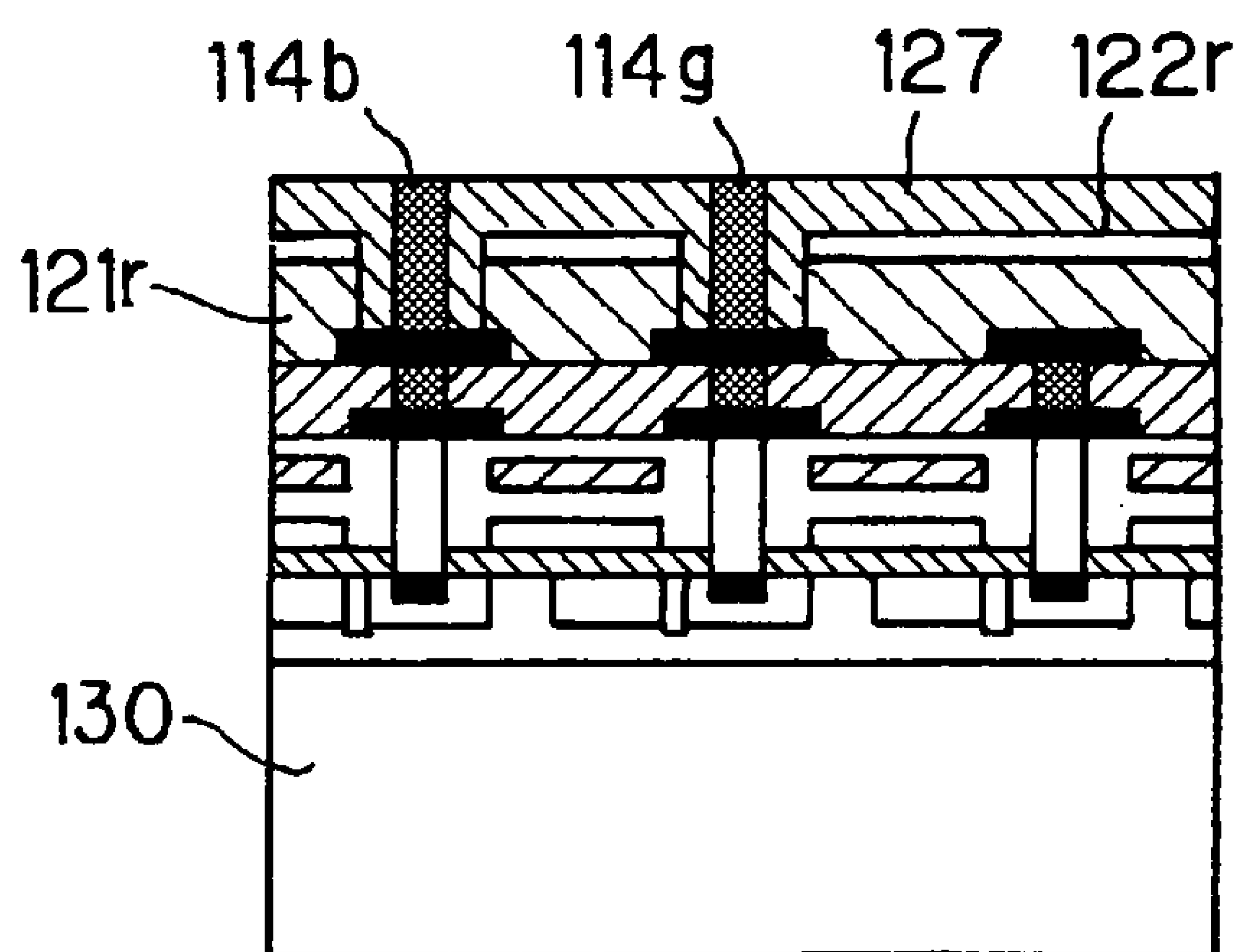



FIG. 17B

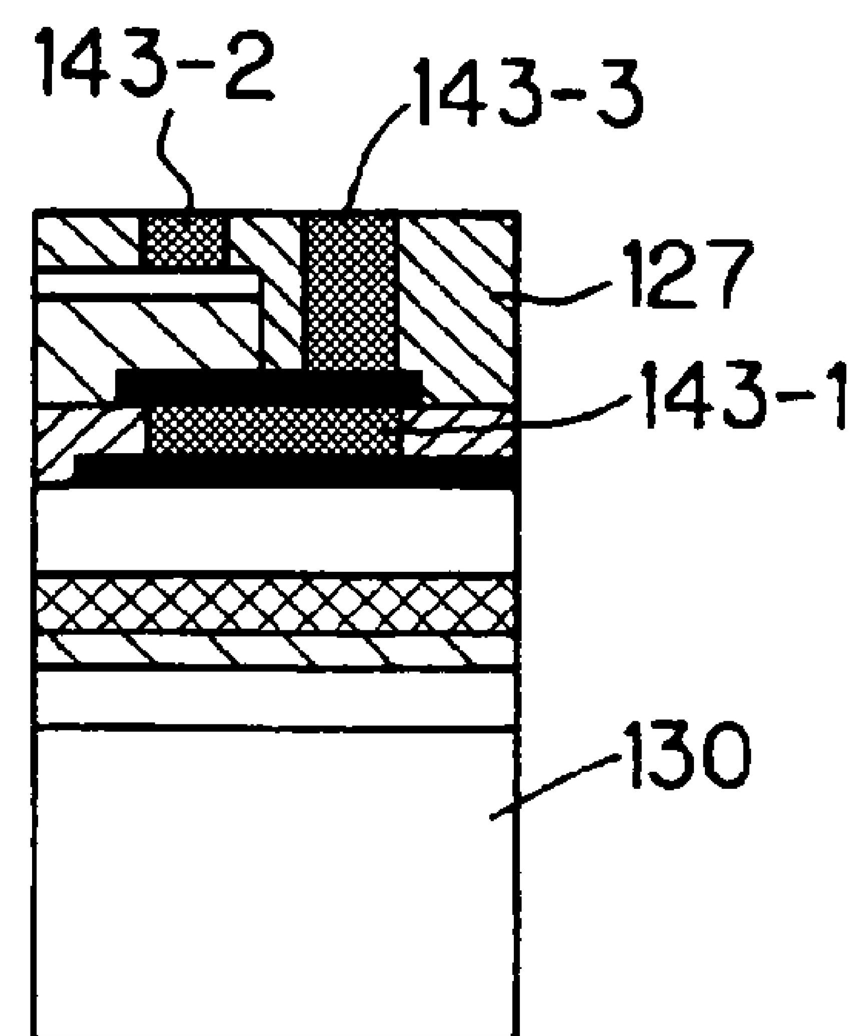


FIG. 18A

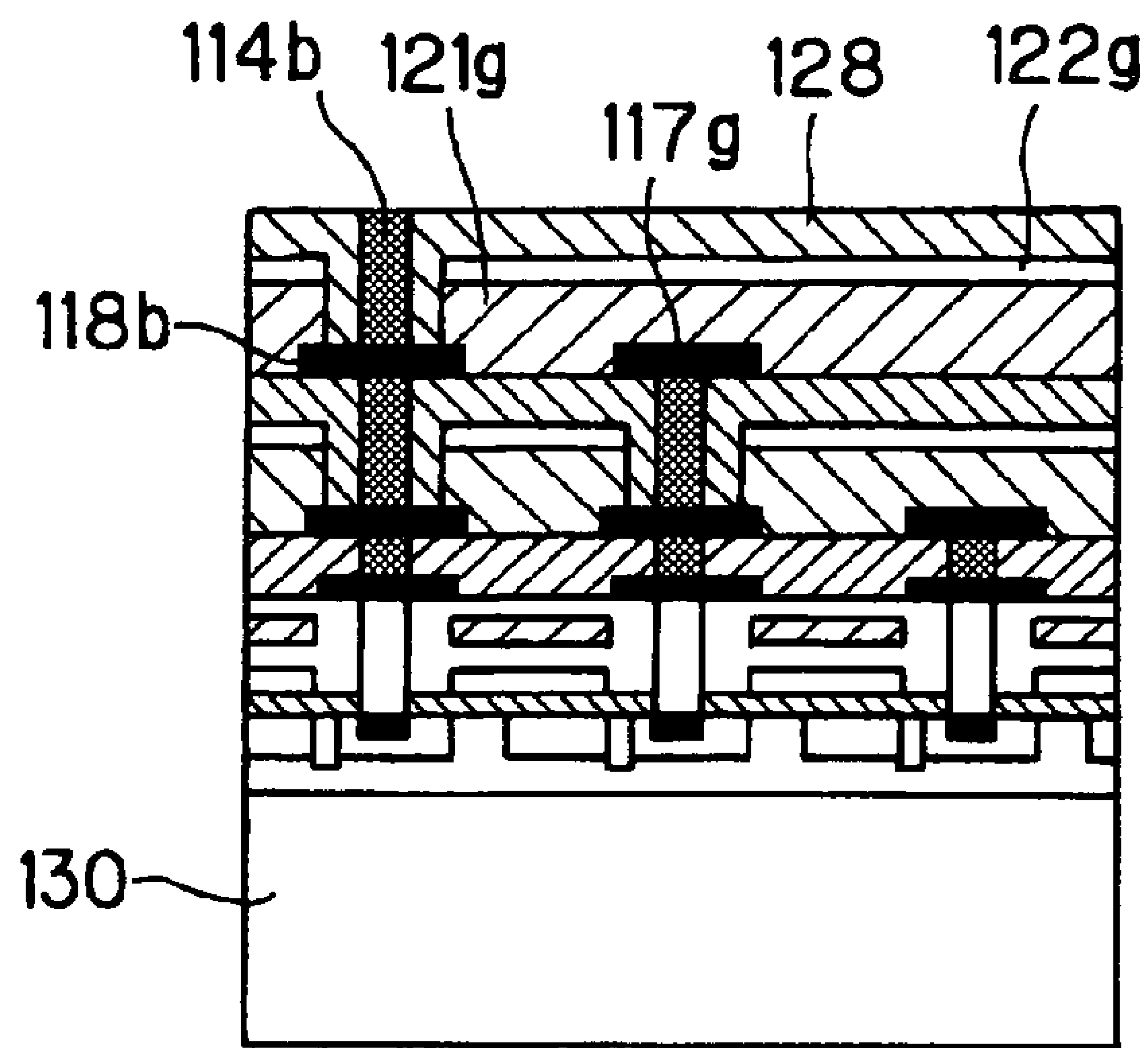



FIG. 18B

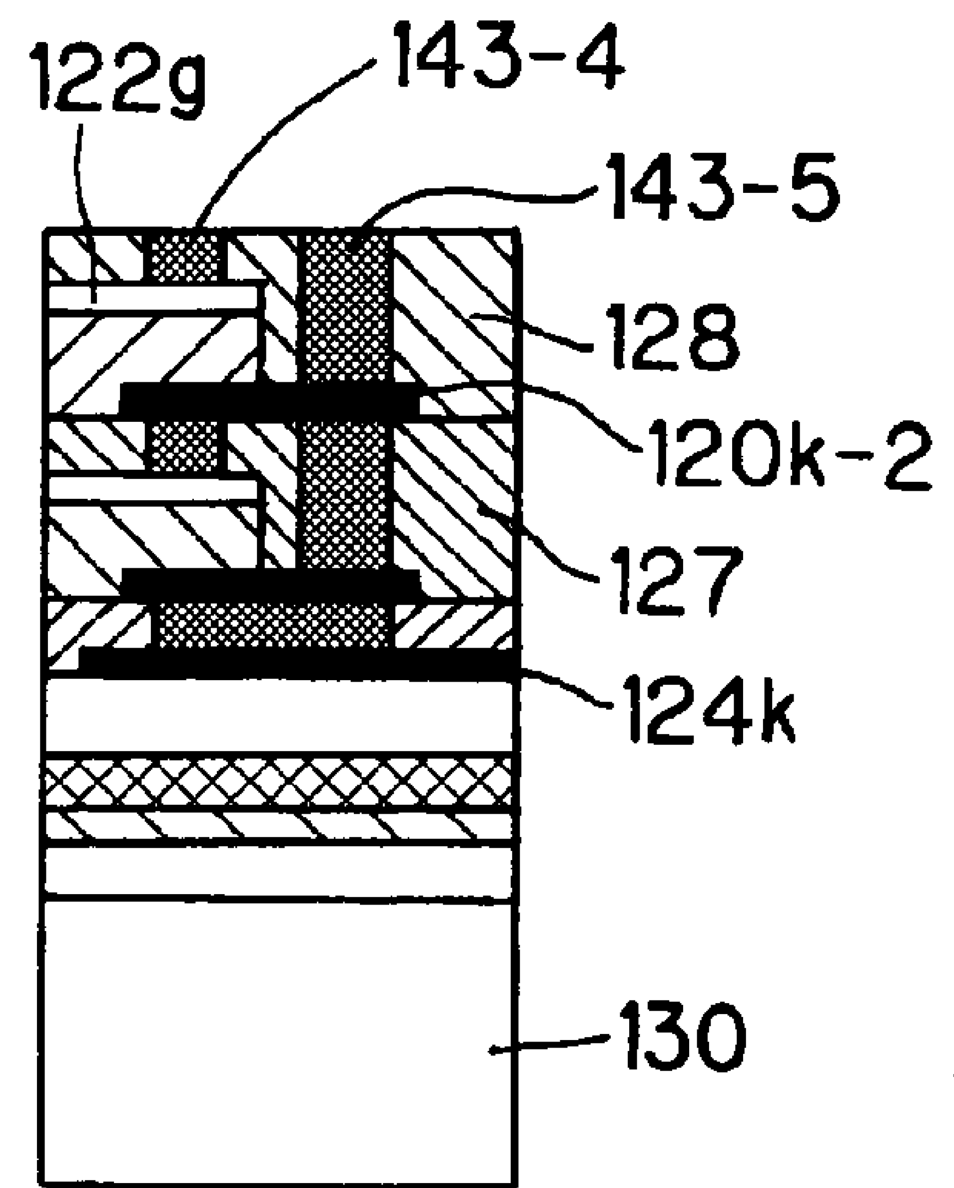



FIG. 19A

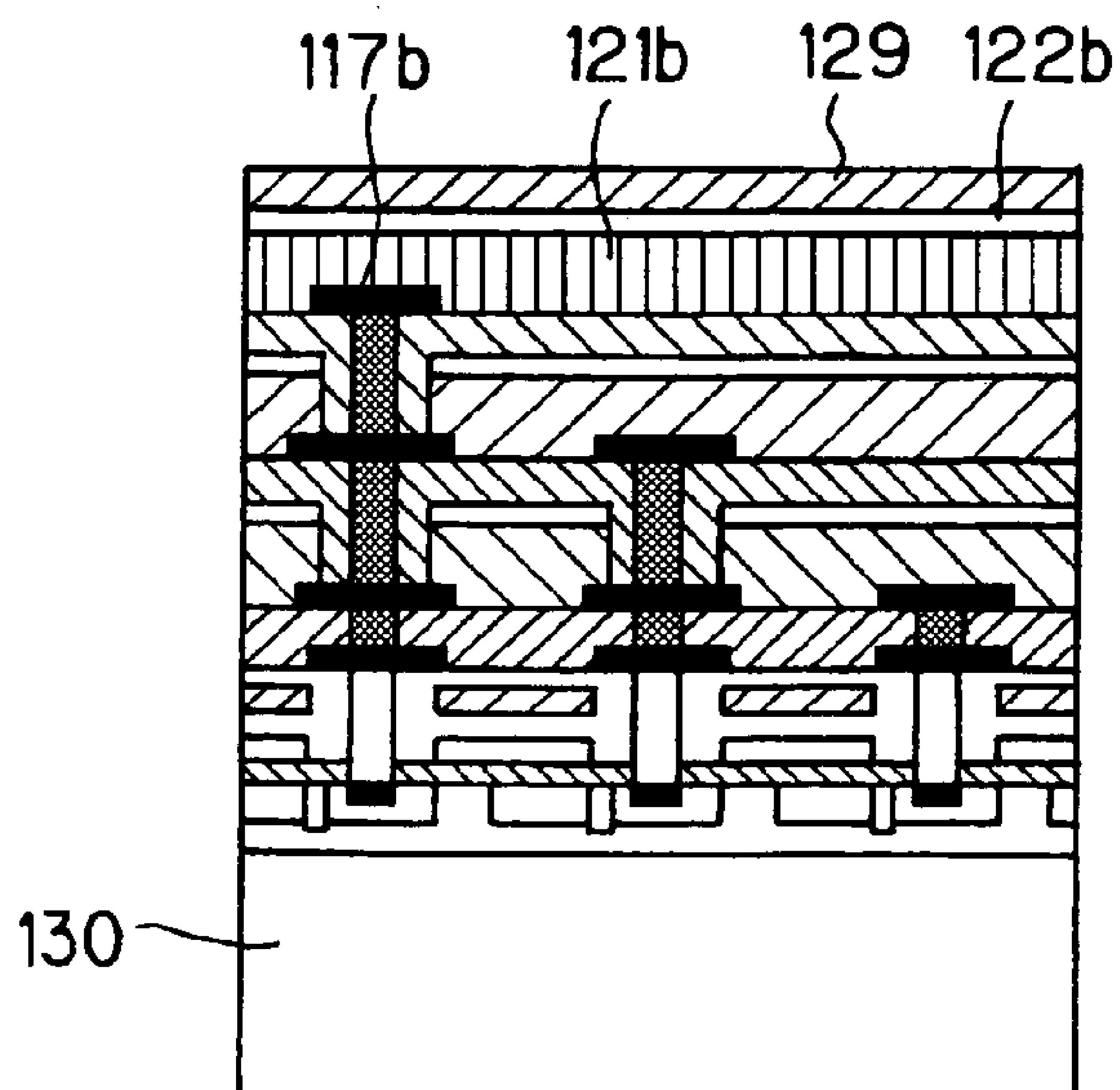



FIG. 19B

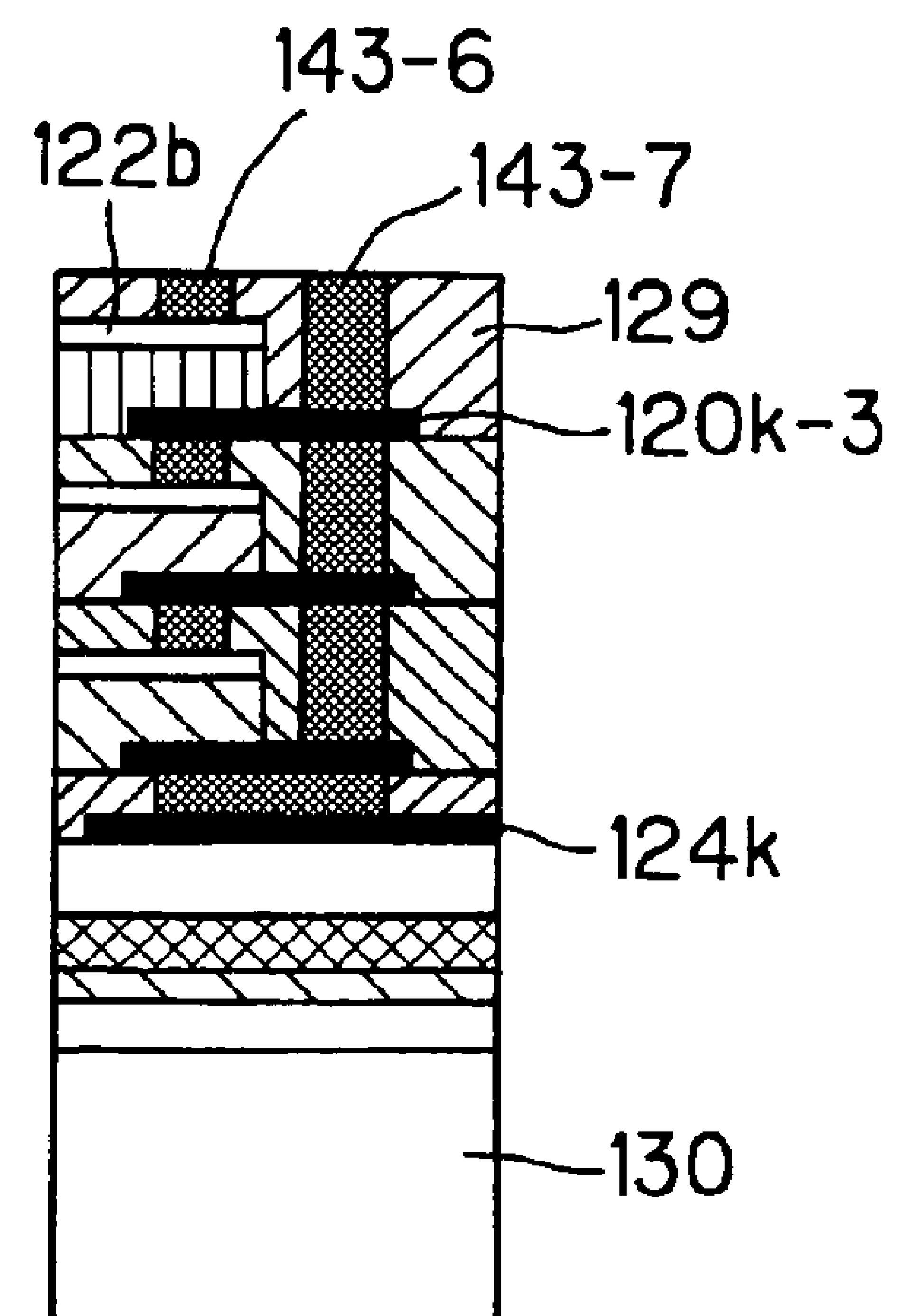


FIG. 20A

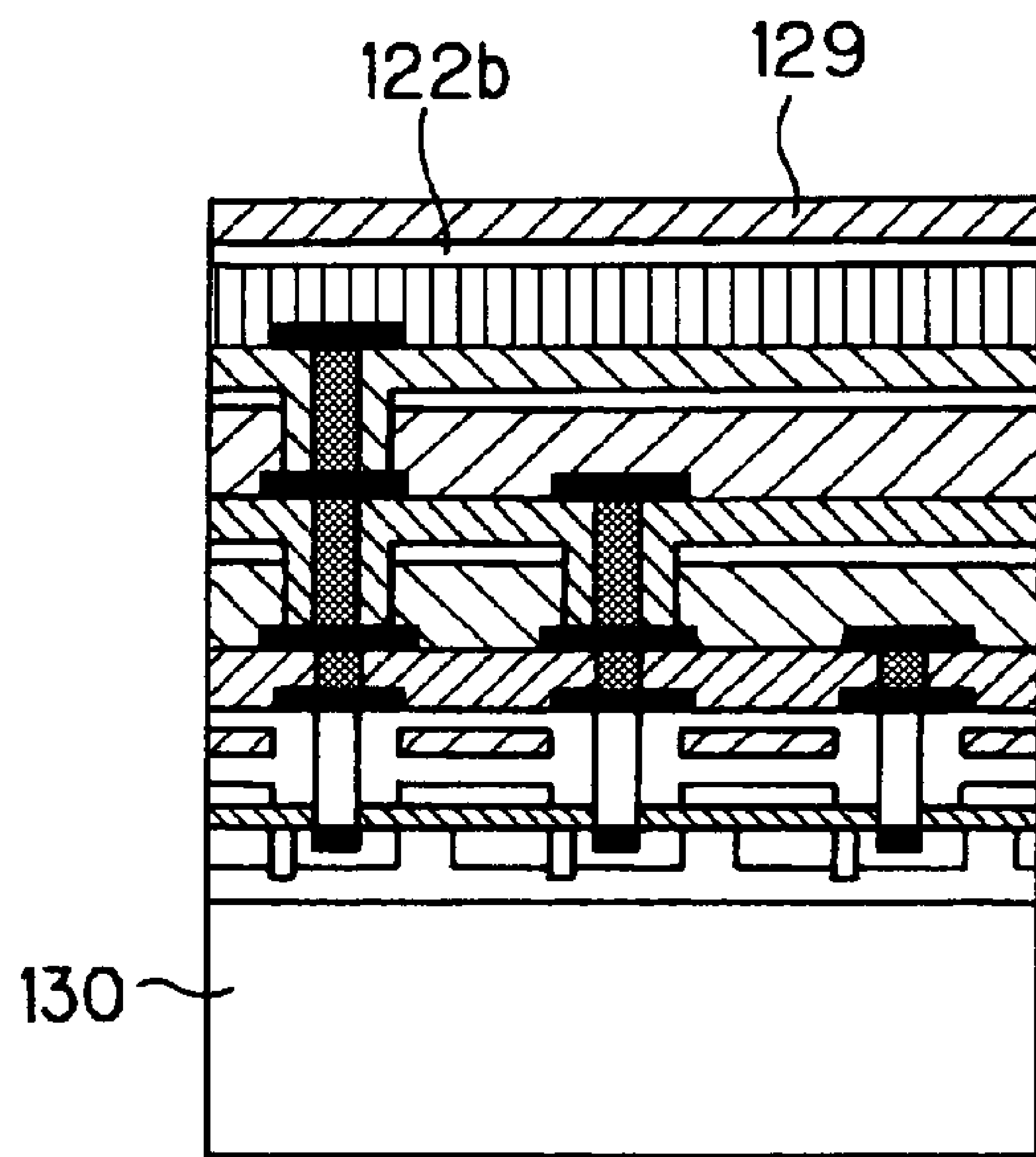



FIG. 20B

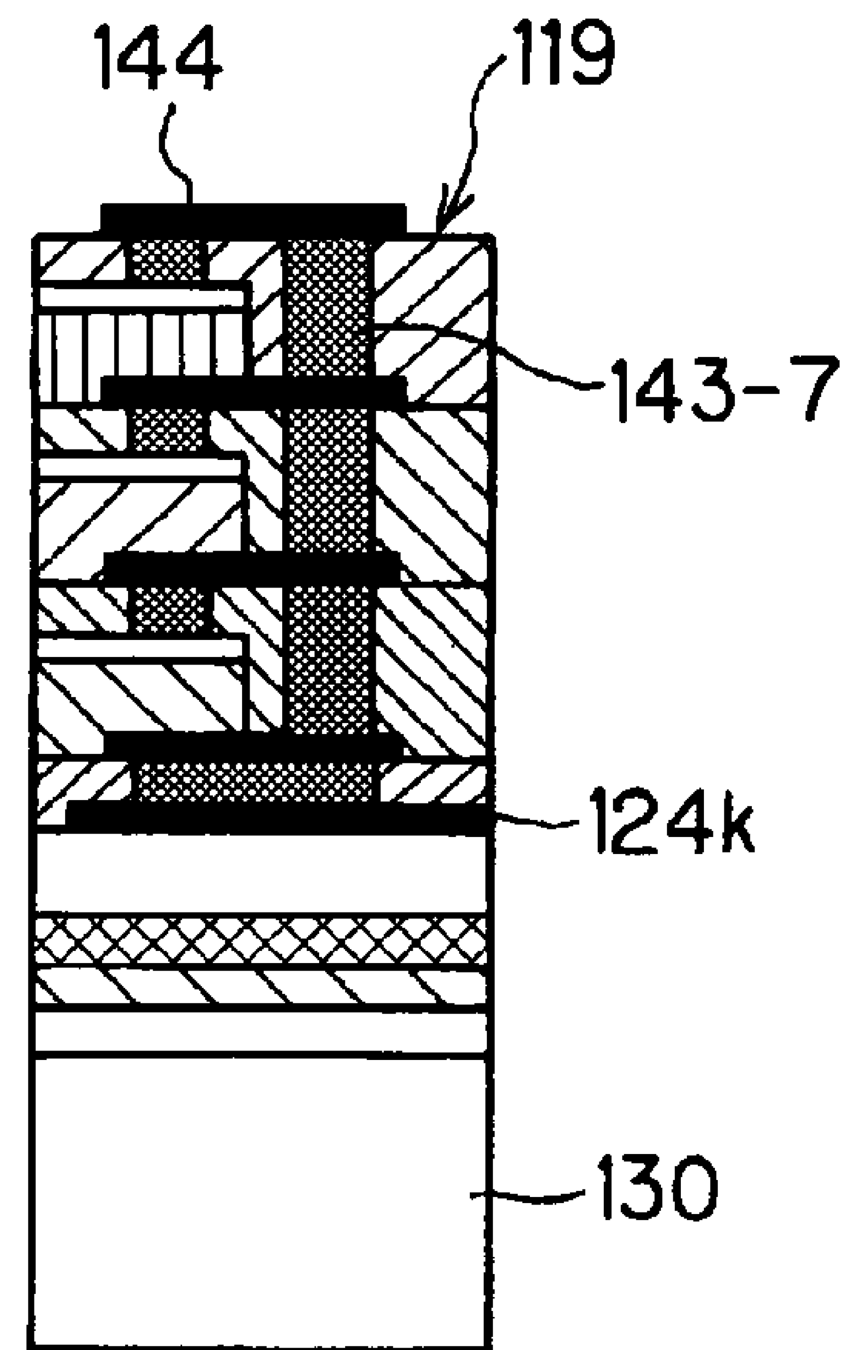



FIG. 21A

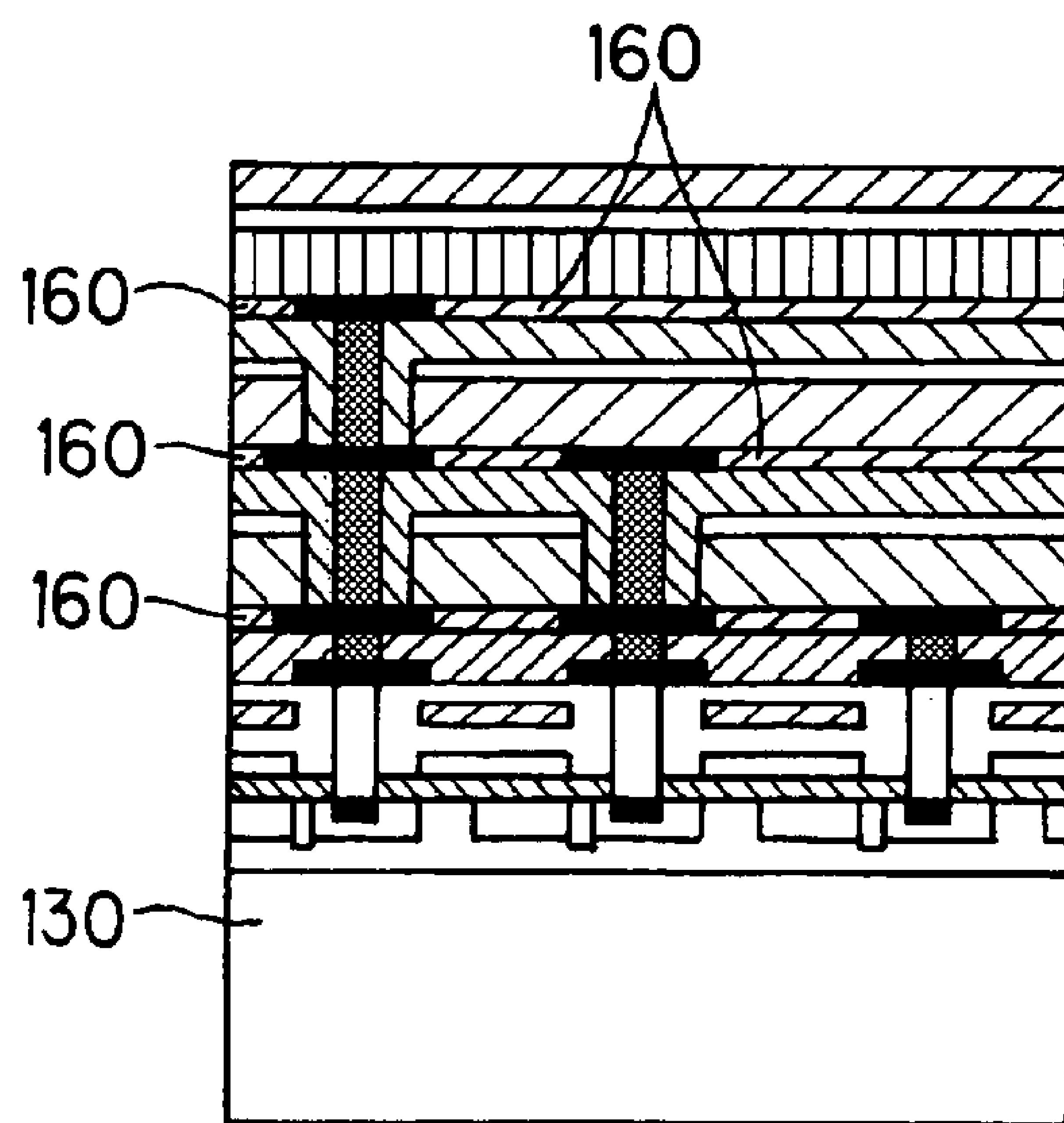



FIG. 21B

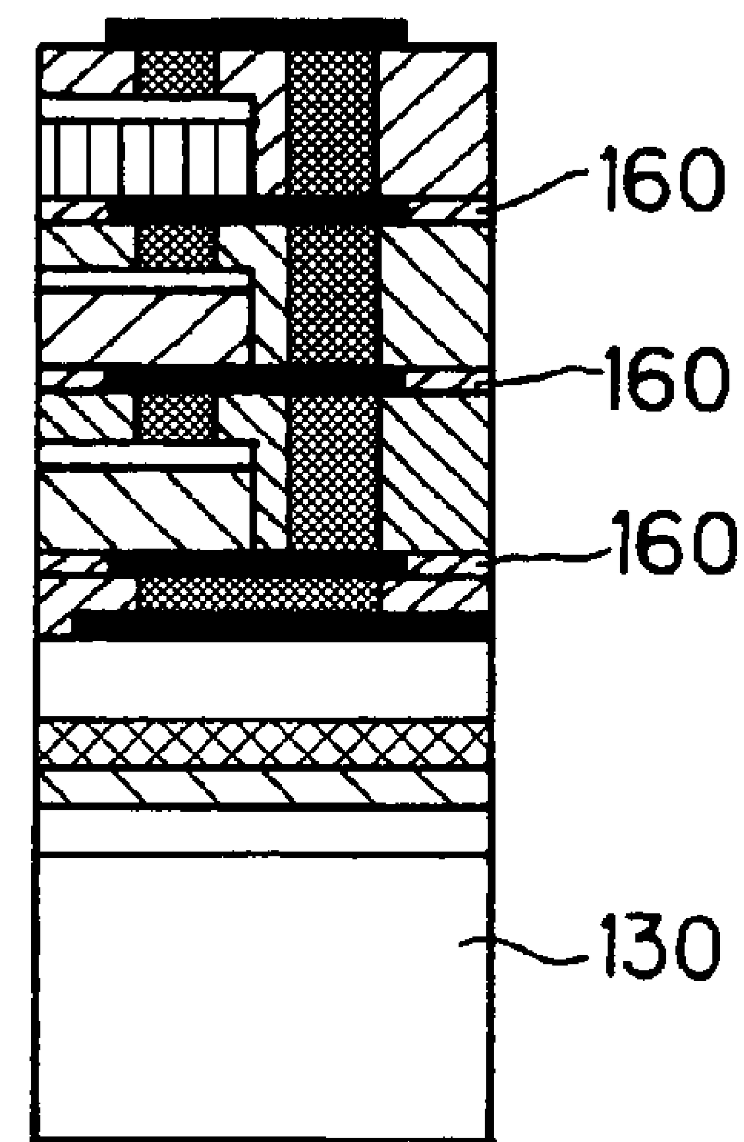


FIG. 22A

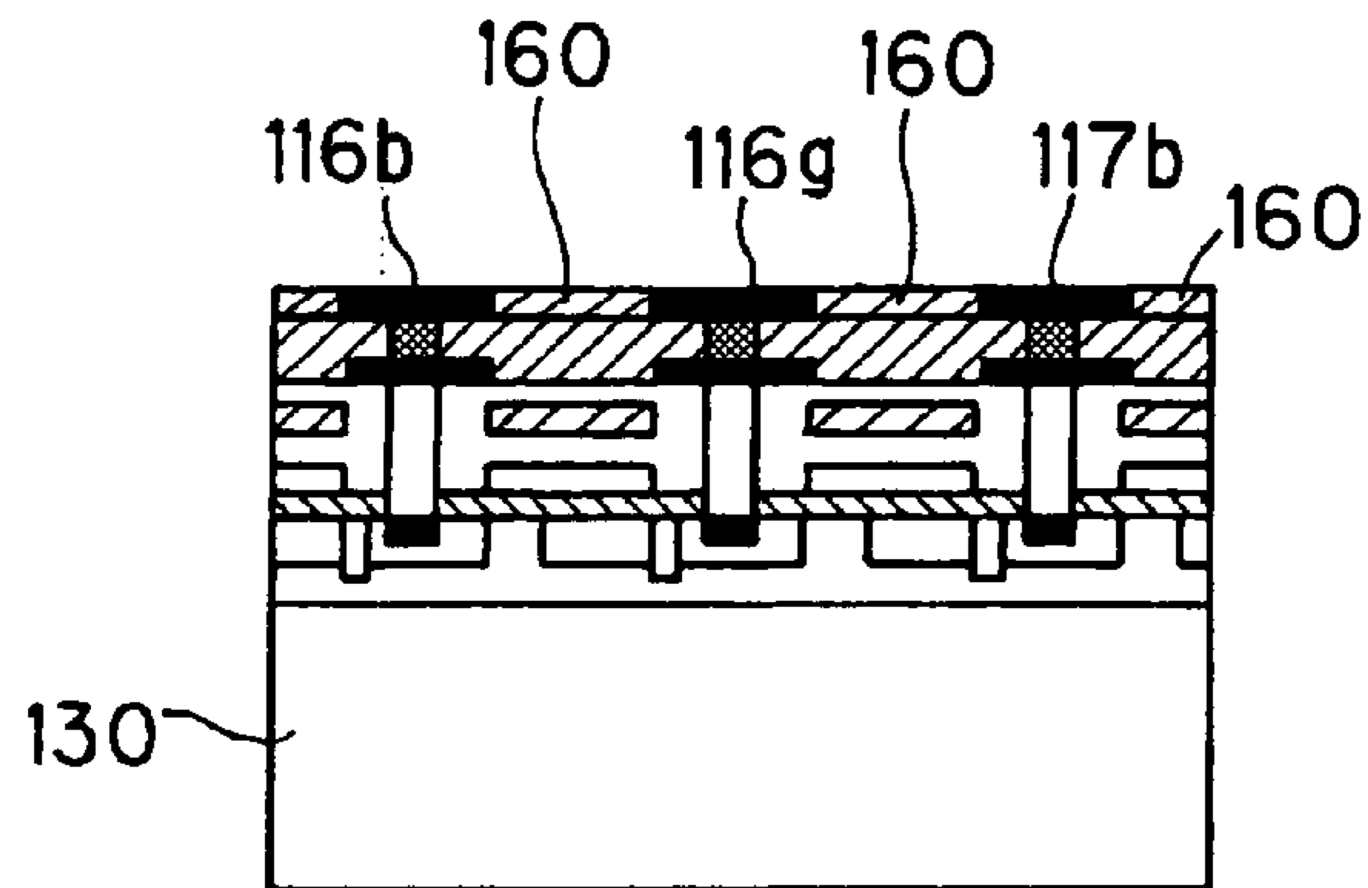



FIG. 22B

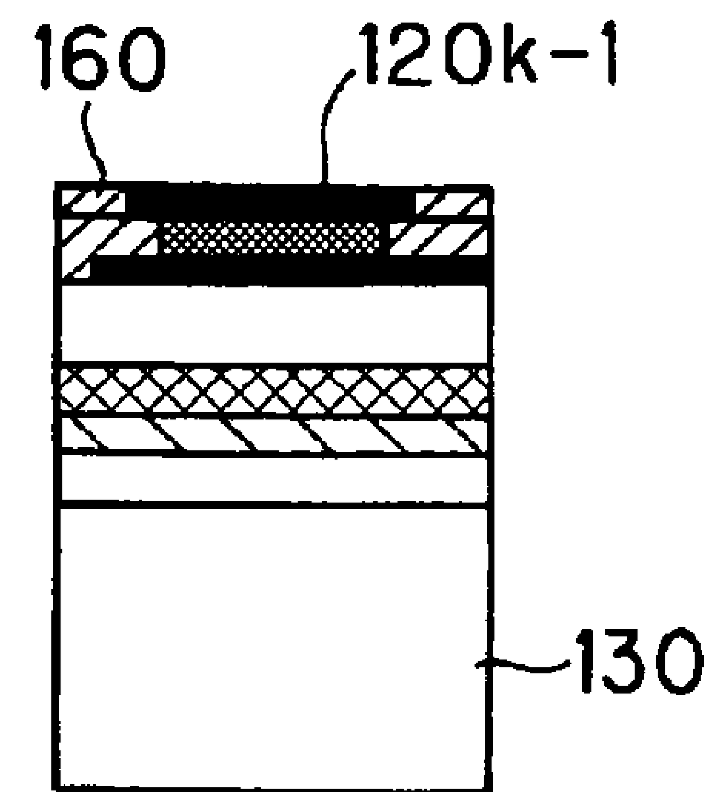



FIG. 23A

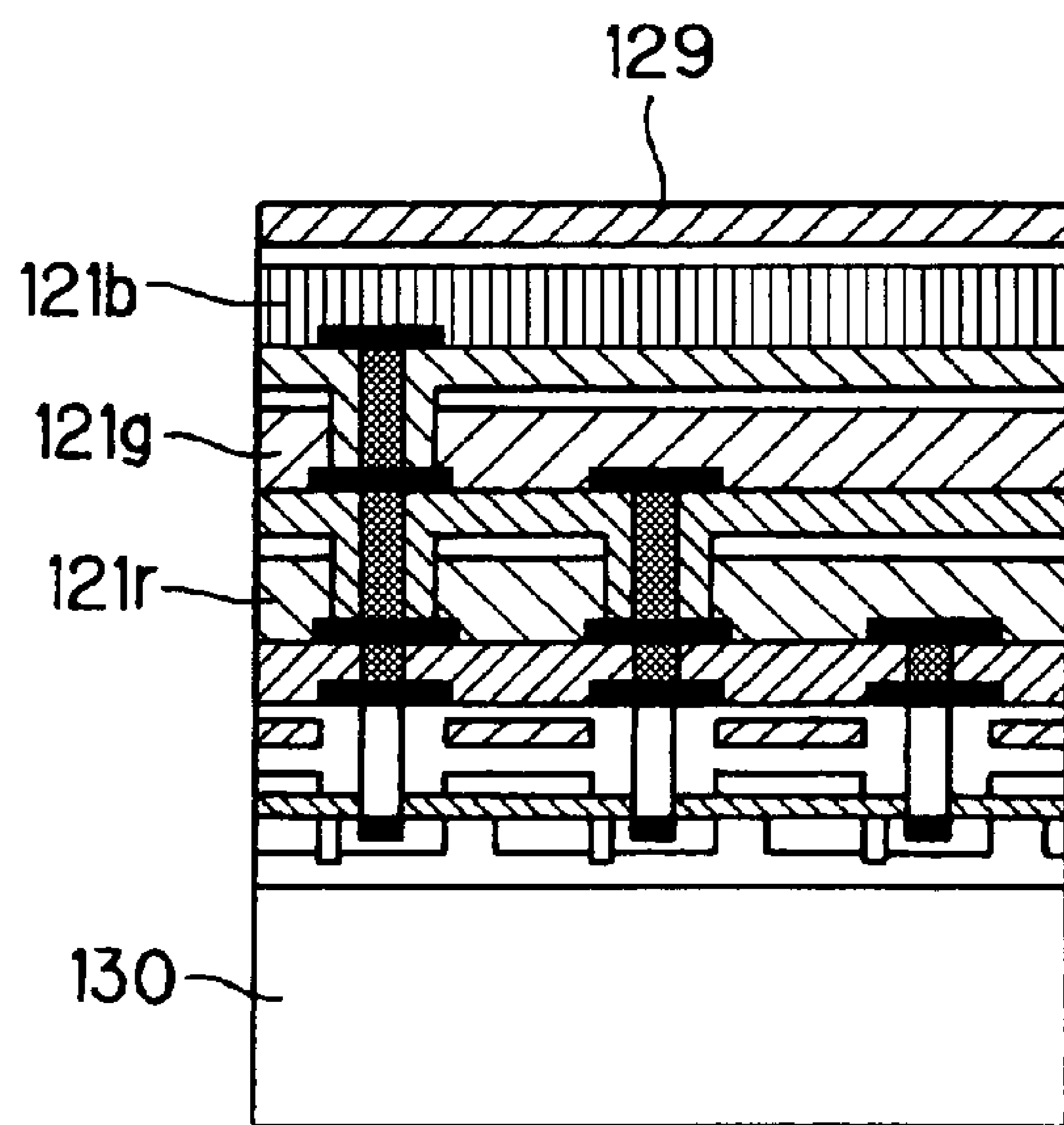



FIG. 23B

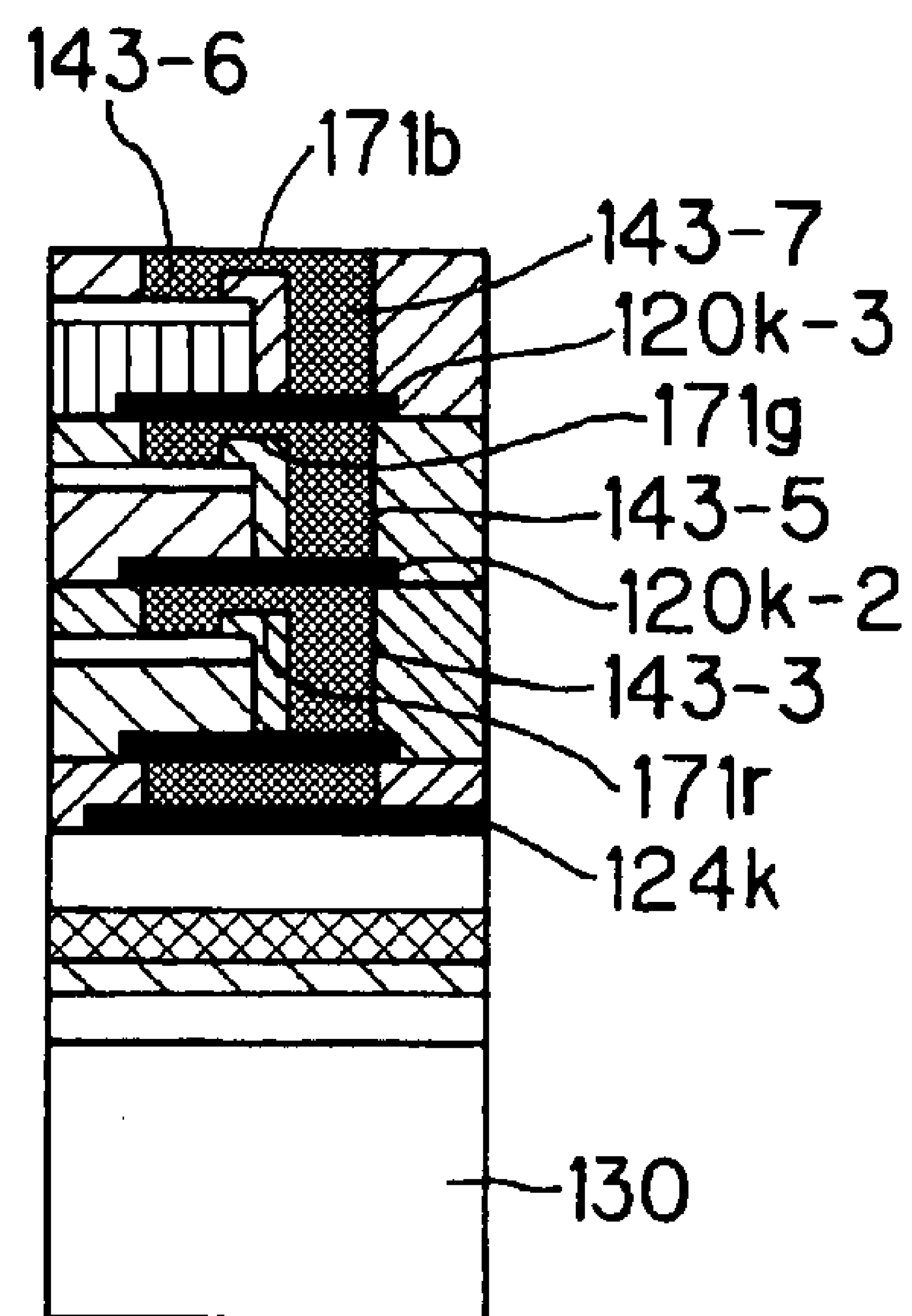


FIG. 24A

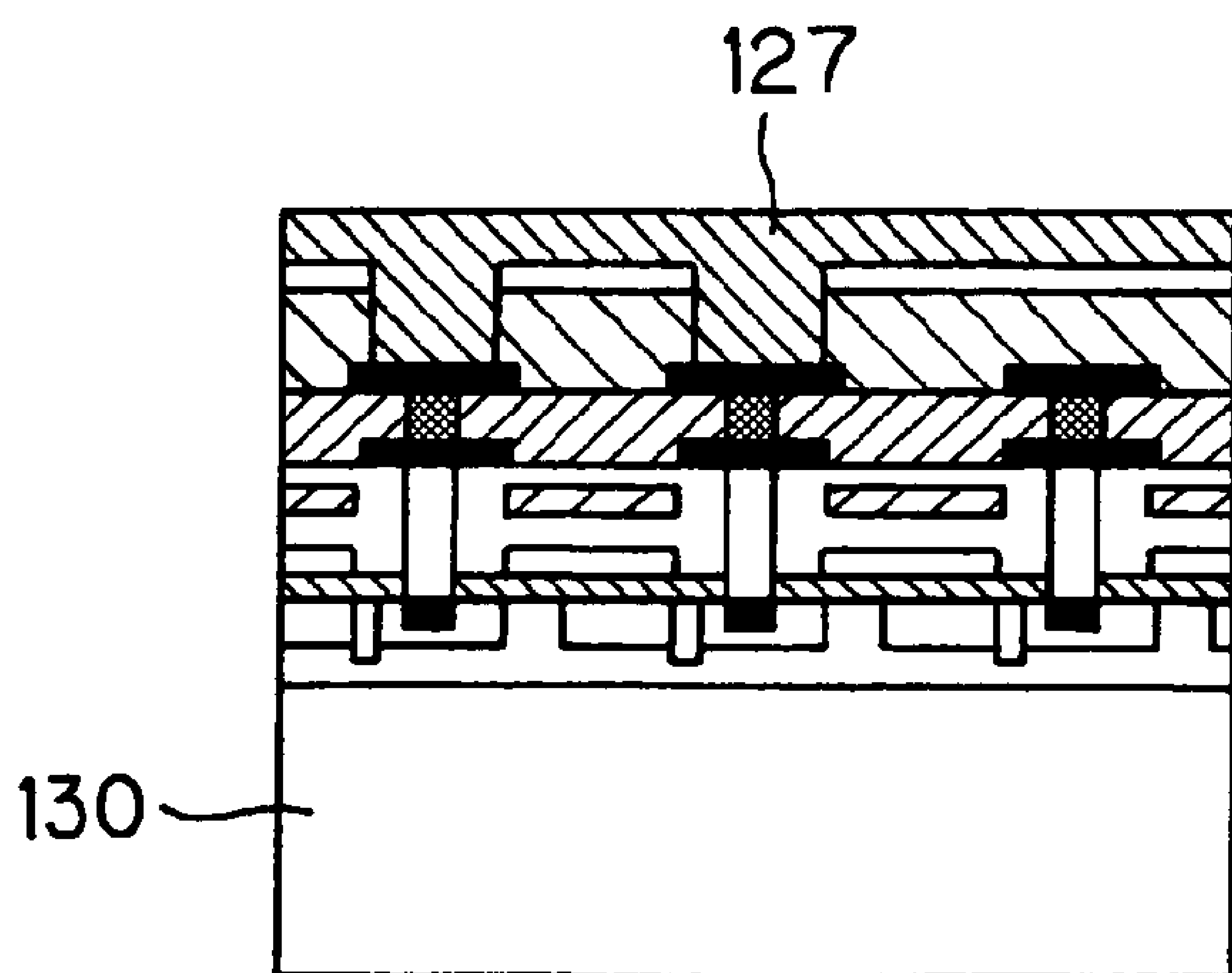



FIG. 24B

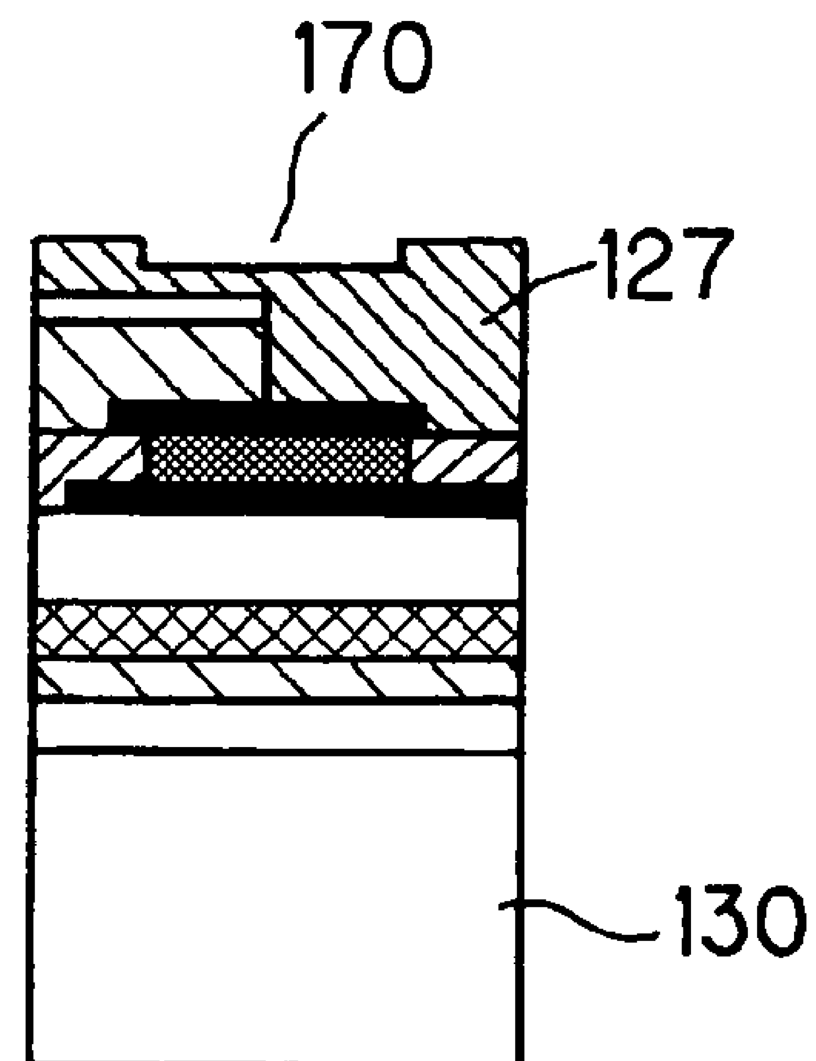



FIG. 25A

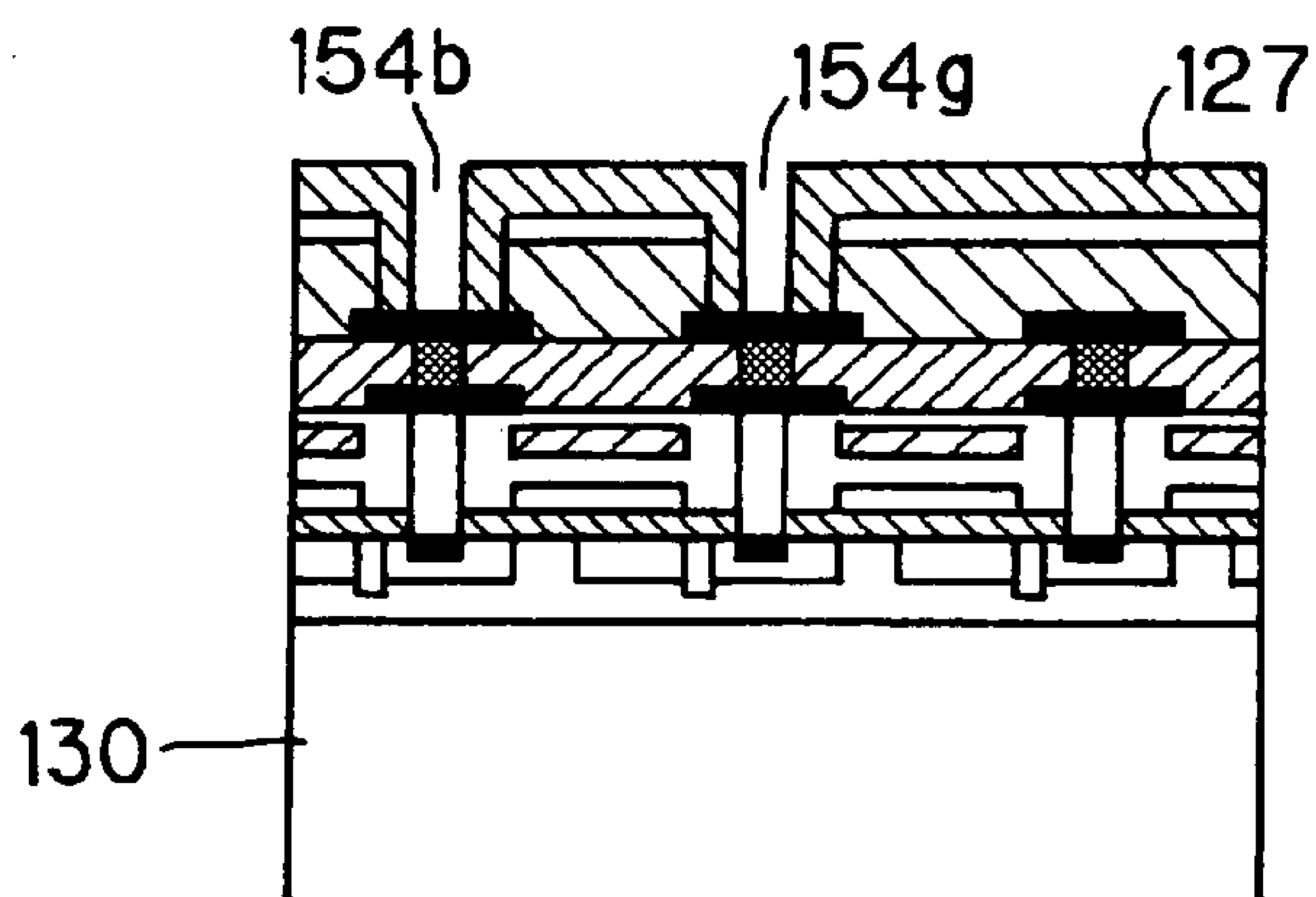



FIG. 25B

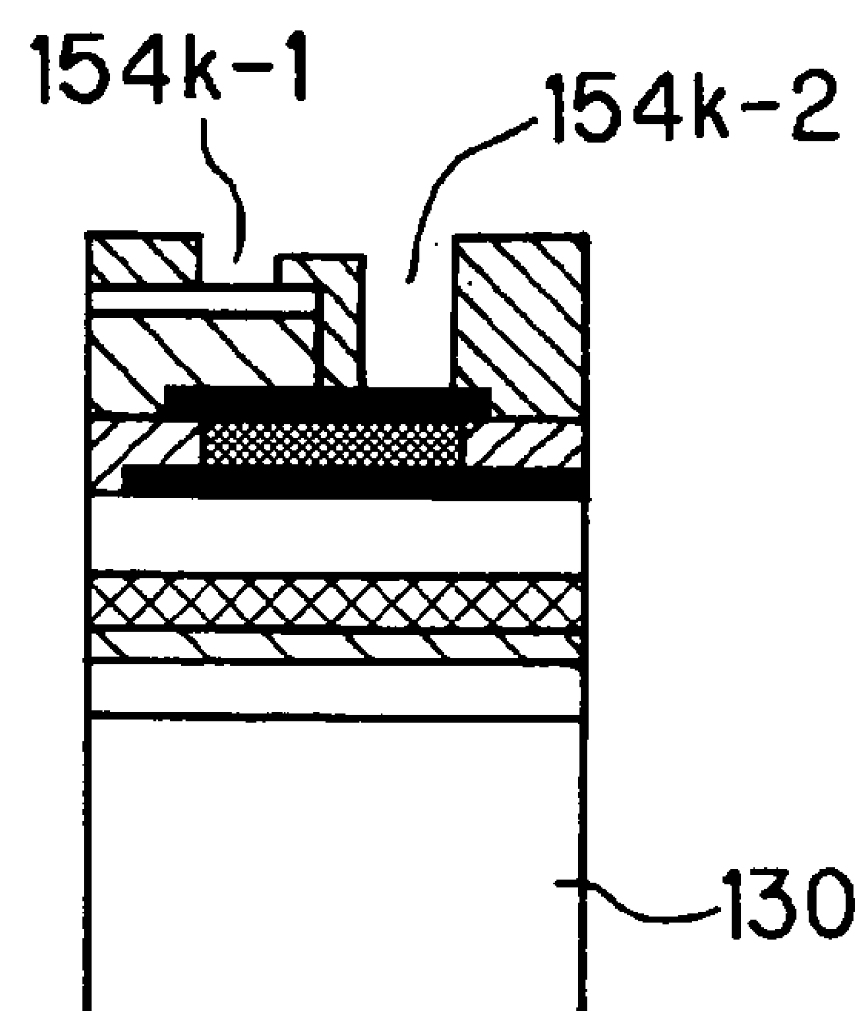



FIG. 26A

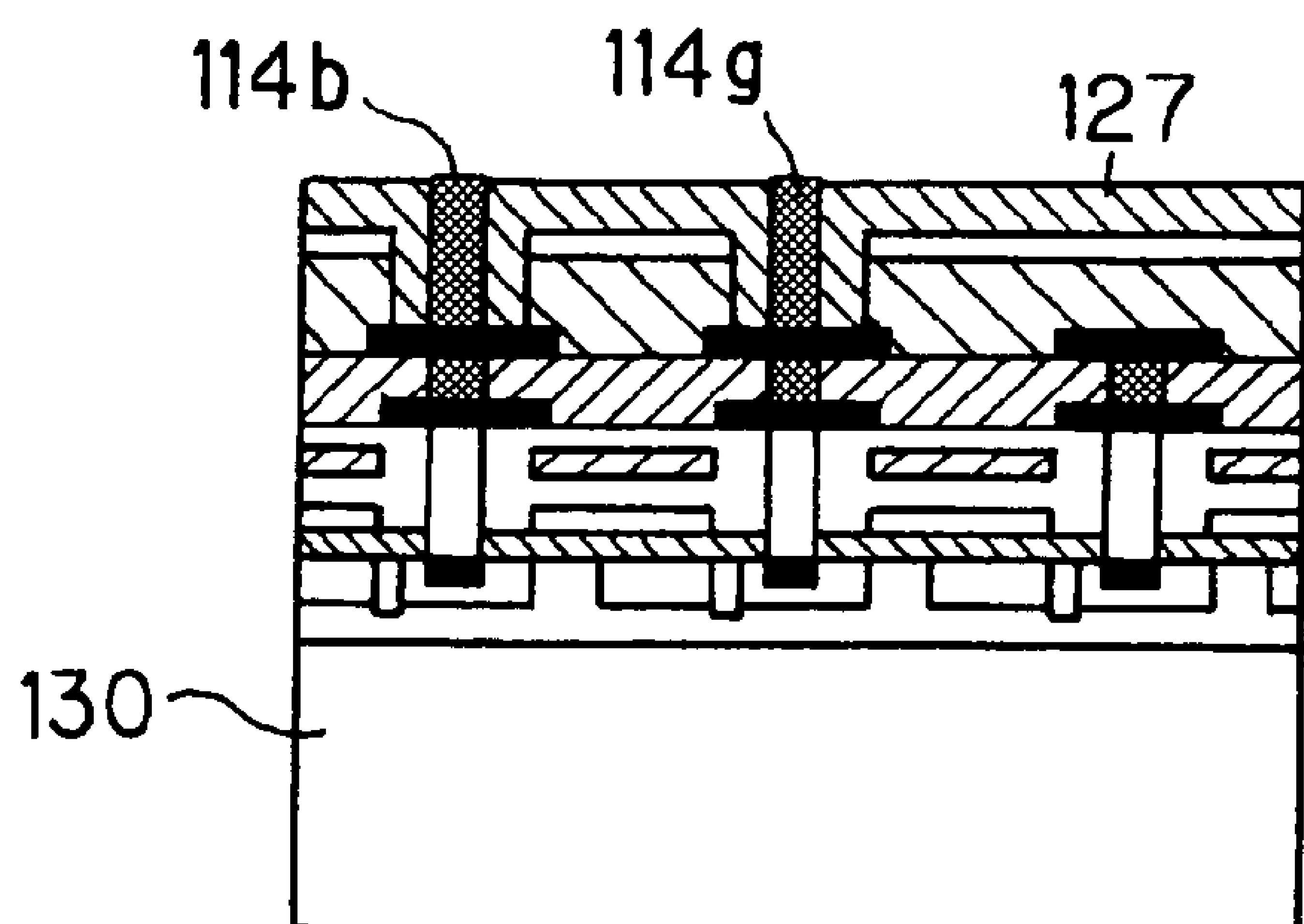
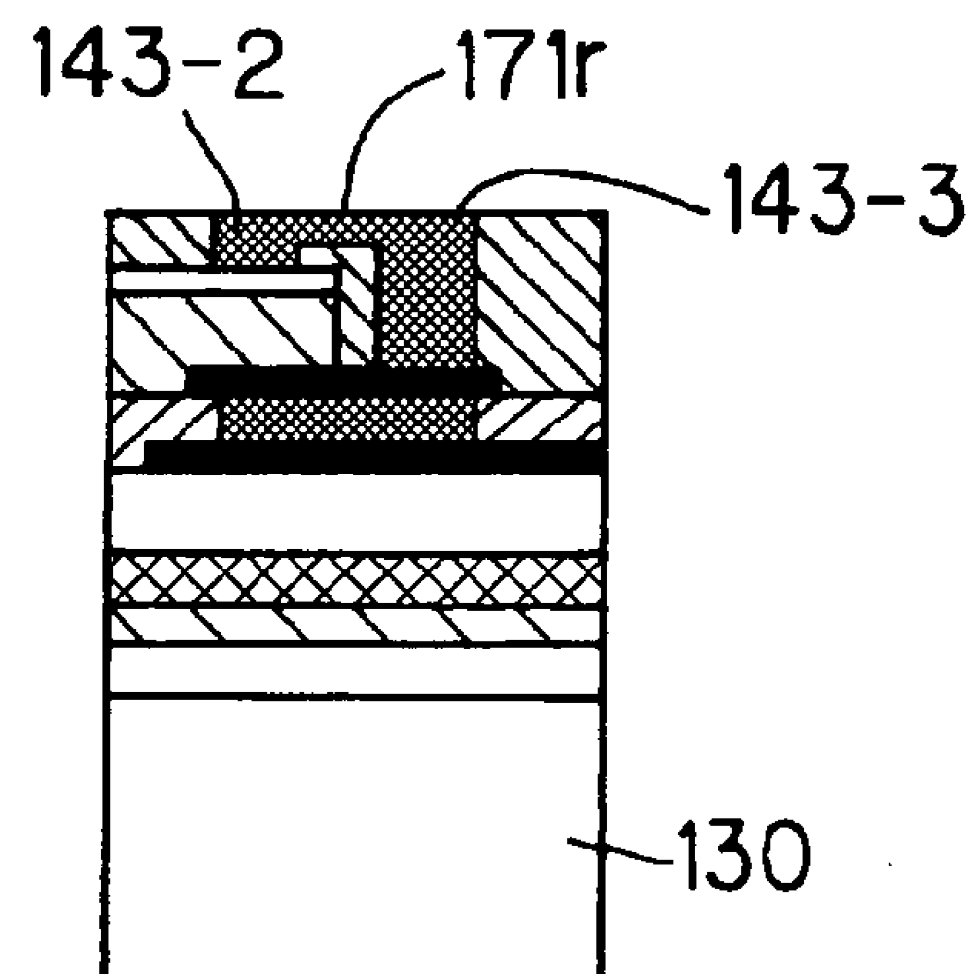



FIG. 26B



# PHOTOELECTRIC CONVERTING FILM STACK TYPE SOLID-STATE IMAGE PICKUP DEVICE, AND METHOD OF PRODUCING THE SAME

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a photoelectric converting film stack type solid-state image pickup device in which a plurality of photoelectric converting films that generate charges corresponding to the amount of received light are stacked on a semiconductor substrate, and more particularly to a photoelectric converting film stack type solid-state image pickup device in which the number of production steps is decreased, the performance is improved, and the production cost is reduced, and a method of producing such a device.

2. Description of the Related Art

In a CCD solid-state image pickup device or a CMOS solid-state image pickup device which is mounted on a digital camera, a large number of photoelectric converting elements (photodiodes) serving as light receiving portions, and signal read circuits which read out photoelectric conversion signals obtained in the photoelectric converting elements are formed on the surface of a semiconductor substrate. The signal read circuits are configured by, in the case of a CCD device, charge transfer circuits and transfer electrodes, or by, in the case of a CMOS device, MOS transistor circuits and signal lines.

In the related-art solid-state image pickup device, therefore, many light receiving portions and signal read circuits must be formed on the same surface of a semiconductor substrate, thereby producing a problem in that the area for the light receiving portions cannot be increased.

The related-art single-type solid-state image pickup device has a configuration in which one of color filters of, for example, red (R), green (G), and blue (B) is stacked on each of light receiving portions, so that the light receiving portion detects a light signal of the one color. In the position of a light receiving portion which detects light of, for example, red, therefore, blue and green signals are obtained by interpolating detection signals of surrounding light receiving portions which detect blue light and green light, respectively. This causes a false color, and reduces the resolution. Furthermore, blue light and green light incident on a light receiving portion where a red color filter is formed do not contribute to photoelectric conversion, but are absorbed as heat into the color filter, thereby producing another problem in that the light use efficiency is poor and the sensitivity is low.

As described above, the related-art solid-state image pickup device has various problems. On the other hand, in such a device, the number of pixels is advancing. At present, a large number or several millions of pixels or light receiving portions are integrated on one chip of a semiconductor substrate, and the size of an opening of each of the light receiving portions is near the order of the wavelength. Consequently, a CCD device and a CMOS device are hardly expected to configure an image sensor which can solve the above-discussed problems, and which is superior in image quality and sensitivity than the related-art one.

Therefore, attention is again paid to the structure of a solid-state image pickup device which is disclosed in, for example, JP-A-58-103165. The solid-state image pickup device has a structure where a red-detection photosensitive layer, a green-detection photosensitive layer, and a blue-detection photosensitive layer are stacked by a film growth technique on a semiconductor substrate in which signal read circuits are formed on the surface, these photosensitive layers are used as light receiving portions, and photoelectric conversion signals obtained in the photosensitive layers are supplied to the outside by the signal read circuits. Namely, the solid-state image pickup device has a structure of a photoelectric converting film stack type.

In this structure, it is not required to dispose the light receiving portions on the surface of the semiconductor substrate. Therefore, restrictions on the design of the signal read circuits are largely eliminated, and the light use efficiency of incident light is improved, so that the sensitivity is enhanced. Moreover, one pixel can detect light of the three primary colors or red, green, and blue. Therefore, the resolution is improved, and a false color does not occur. As a result, it is possible to solve the above-discussed problems of the related-art CCD or CMOS solid-state image pickup device.

Recently, photoelectric converting film stack type solid-state image pickup devices disclosed in JP-A-2002-83946, JP-T-2002-502120, JP-T-2003-502847 and Japanese Patent No. 3,405,099 have been proposed. An organic semiconductor or nanoparticles are used as the photosensitive layers.

When a photoelectric converting film stack type solid-state image pickup device is produced, production of a signal read circuit on the side of a semiconductor substrate is performed in the same manner as the related-art CCD or CMOS image sensor, and hence the production technique of a semiconductor device is used as it is in the production. Furthermore, also photoelectric converting films stacked on a semiconductor substrate, and electrode films and insulating films sandwiching the photoelectric converting films are easily produced by a film growing method using the printing technique, the spraying method, the vacuum depositing method, the sputtering method, the CVD method, or the like.

In a photoelectric converting film stack type solid-state image pickup device, however, it is necessary to form lines which connect a signal read circuit formed on a surface portion of a semiconductor substrate to electrode films of photoelectric converting films stacked on the circuit. Moreover, the lines must be formed as longitudinal lines which are perpendicular to the planes of the electrode films and the surface of the semiconductor substrate.

The longitudinal lines are produced in the following manner. In the related art disclosed in, for example, JP-A-2002-83946, when a photoelectric converting film is grown, longitudinal line forming portions passing through the photoelectric converting film are etched away, and conductors are buried, and, when an electrode film is formed on the photoelectric converting film, longitudinal line forming portions of the electrode film are etched away, and conductors are buried. The work is repeated several times, or at each time when a film is grown. Consequently, there arises a problem in that the number of steps of producing longitudinal lines is increased and the production cost is high.

The longitudinal lines are produced while stacking the photoelectric converting films on the semiconductor substrate. When the number of steps of producing the longitudinal lines is large, the photoelectric converting films are exposed to a high temperature during a process of producing the longitudinal lines, and therefore there is a possibility that the materials of the photoelectric converting film are deteriorated and the performance of photoelectric conversion is adversely affected. Consequently, there is also a request for reducing the number of steps of producing longitudinal lines as far as possible.

The process of producing longitudinal lines consists of repetition of, for example, application of a resist film, exposure, opening of longitudinal line portions by etching, burying of longitudinal line conductors, removal of the resist

films, and polishing of the surface. When the process of producing longitudinal lines is interposed between formation of a photoelectric converting film and that of an electrode film on the photoelectric converting film, the interface between the photoelectric converting film and the electrode film is damaged by application and removal of a resist film, and polishing, and there is a possibility that the performance of photoelectric conversion is deteriorated. Because of this reason also, the number of steps of producing longitudinal lines must be reduced.

## SUMMARY OF THE INVENTION

It is an object of the invention to provide a photoelectric converting film stack type solid-state image pickup device in which the number of steps of producing longitudinal lines is reduced so as to lower the production cost and the performance of photoelectric conversion is improved, and a method of producing the device.

According to the invention, there is provided a method of producing a photoelectric converting film stack type solid-state image pickup device, in which the photoelectric converting film stack type solid-state image pickup device comprises a plurality of photoelectric converting films stacked via an insulating layer, the photoelectric converting films being above a semiconductor substrate in which a signal read circuit is formed, and in which each of the photoelectric converting films is sandwiched between a pixel electrode film patterned for each pixel and an opposing electrode film opposed to the pixel electrode film, the method comprising connecting the pixel electrode film for an upper one of the photoelectric converting films to the signal read circuit by a longitudinal line passing through a lower one of the photoelectric converting films, wherein the method comprises: stacking a first opposing electrode film on the lower photoelectric converting film, in succession to stacking the lower photoelectric converting film; forming a first opening at a predetermined place of the first opposing electrode film and the lower photoelectric converting film after stacking of the first opposing electrode film and in the same step; filling the first opening with the insulating layer; forming a second opening which is smaller in diameter than said first opening; and filling the second opening with a conductive material, so as to form a portion which passes through the lower photoelectric converting film in the longitudinal line.

According to the configuration, the number of production steps is reduced, and the interface between a photoelectric converting film and an opposing electrode film can be prevented from being damaged. Therefore, the production cost can be lowered, and the performance of photoelectric conversion can be improved.

According to the invention, there is provided a photoelectric converting film stack type solid-state image pickup device comprising: a semiconductor substrate in which a signal read circuit is formed; a plurality of photoelectric converting films stacked via an insulating layer, the photoelectric converting films being above the semiconductor substrate, in which each of the photoelectric converting films is sandwiched between a pixel electrode film patterned for each pixel and an opposing electrode film opposed to the pixel electrode film, wherein the pixel electrode film of an upper one of the photoelectric converting films is connected to the signal read circuit by a longitudinal line passing through a lower one of the photoelectric converting films, and wherein, in the longitudinal line, a passing portion which passes through the lower photoelectric converting film is formed by filling an opening with a conductive material, the opening being formed from a same plane of the pixel electrode film stacked on the lower photoelectric converting film to an upper end face of the insulating layer stacked above the photoelectric converting film.

According to the configuration, the number of production steps is reduced, and the interface between a photoelectric converting film and an opposing electrode film can be prevented from being damaged. Therefore, the production cost can be lowered, and the performance of photoelectric conversion can be improved.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, further comprising: a first conductive film which is patterned simultaneously with patterning of the lower pixel electrode film, the first conductive film being at a portion of the same plane with which the passing portion is in contact; and a second conductive film which is patterned simultaneously with patterning of the upper pixel electrode film, the second conductive film being on the upper end face of the insulating layer with which the passing portion is in contact.

According to the configuration, the production accuracy of the passing portion of the longitudinal line is improved.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, further comprising a smoothing transparent insulating film on a portion where a conductive film is removed away by patterning the pixel electrode film.

According to the configuration, the smoothness of the photoelectric converting film is enhanced, and the performance of photoelectric conversion can be further improved.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, wherein a plurality of photoelectric converting films comprises: a red-detection photoelectric converting film having a peak in a red spectral sensitivity characteristic; a green-detection photoelectric converting film having a peak in a green spectral sensitivity characteristic; and a blue-detection photoelectric converting film having a peak in a blue spectral sensitivity characteristic.

According to the configuration, image signals of the three primary colors can be obtained, and hence a color image can be taken.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, further comprising: a first longitudinal line for the opposing electrode film, the first longitudinal line upstanding at a place which is an end portion of said photoelectric converting film, and at a place which is separate from the photoelectric converting film; a second longitudinal line for the opposing electrode film, the second longitudinal line being disposed for each of the opposing electrode films, and extending from an upper end face of the insulating layer stacked on the opposing electrode film of each of the photoelectric converting films, to the opposing electrode film; and a connecting conductive film which electrically connects, on upper end faces of the insulating layer, the second longitudinal line with the first longitudinal line.

According to the configuration, the same bias potential can be applied to the opposing electrode films easily.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, wherein those other than an uppermost one of the connecting conductive films are formed simultaneously with patterning of a conductive film formed on the upper end face of the insulating layer to form the pixel electrode film.

According to the configuration, a portion for applying a bias potential to the opposing electrode films can be constituted easily.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, wherein a recess is disposed in the upper end face of the insulating layer between the first longitudinal line and the second longitudinal line, and the recess is filled with a conductive material which is identical with the first longitudinal line and the second longitudinal line, wherein the first longitudinal line and the second longitudinal line are electrically connected to each other.

According to the configuration, connection between the first longitudinal line for the opposing electrode film and the second longitudinal line for the opposing electrode film is facilitated. When this configuration is used together with the above-mentioned conductive films, the connection resistance between them can be lowered.

According to the invention, there is provided the photoelectric converting film stack type solid-state image pickup device, wherein the first longitudinal line for the opposing electrode film and the second longitudinal line for the opposing electrode film are formed in a same production step as a longitudinal line which connects the pixel electrode film to the signal read circuit.

According to the configuration, the production cost of the whole photoelectric converting film stack type solid-state image pickup device can be lowered.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a surface diagram of a photoelectric converting film stack type solid-state image pickup device of a first embodiment of the invention;

FIG. **2**A is an enlarged diagram of the inside of the rectangular frame II in FIG. **1**;

FIG. **2**B is an exploded view of a pixel electrode film of a light receiving portion;

FIG. **3** is a cross-sectional diagram taken along the line III-III in FIG. **2**A;

FIG. **4** is a cross-sectional diagram taken along the line IV-IV in FIG. **2**A;

FIG. **5** is a cross-sectional diagram taken along the line V-V in FIG. **2**A;

FIGS. **6**A and **6**B are diagrams showing the production procedure of the photoelectric converting film stack type solid-state image pickup device of the first embodiment;

FIGS. **7**A and **7**B are diagrams showing the production procedure subsequent to FIGS. **6**A and **6**B;

FIGS. **8**A and **8**B are diagrams showing the production procedure subsequent to FIGS. **7**A and **7**B;

FIGS. **9**A and **9**B are diagrams showing the production procedure subsequent to FIGS. **8**A and **8**B;

FIGS. **10**A and **10**B are diagrams showing the production procedure subsequent to FIGS. **9**A and **9**B;

FIGS. **11**A and **11**B are diagrams showing the production procedure subsequent to FIGS. **10**A and **10**B;

FIGS. **12**A and **12**B are diagrams showing the production procedure subsequent to FIGS. **11**A and **11**B;

FIGS. **13**A and **13**B are diagrams showing the production procedure subsequent to FIGS. **12**A and **12**B;

FIGS. **14**A and **14**B are diagrams showing the production procedure subsequent to FIGS. **13**A and **13**B;

FIGS. **15**A and **15**B are diagrams showing the production procedure subsequent to FIGS. **14**A and **14**B;

FIGS. **16**A and **16**B are diagrams showing the production procedure subsequent to FIGS. **15**A and **15**B;

FIGS. **17**A and **17**B are diagrams showing the production procedure subsequent to FIGS. **16**A and **16**B;

FIGS. **18**A and **18**B are diagrams showing the production procedure subsequent to FIGS. **17**A and **17**B;

FIGS. **19**A and **19**B are diagrams showing the production procedure subsequent to FIGS. **18**A and **18**B;

FIGS. **20**A and **20**B are diagrams showing the production procedure subsequent to FIGS. **19**A and **19**B;

FIGS. **21**A and **21**B are cross-sectional diagrams of a photoelectric converting film stack type solid-state image pickup device of a second embodiment of the invention;

FIGS. **22**A and **22**B are cross-sectional diagrams showing the middle of the production of the photoelectric converting film stack type solid-state image pickup device shown FIGS. **21**A and **21**B;

FIGS. **23**A and **23**B are cross-sectional diagrams of a photoelectric converting film stack type solid-state image pickup device of a third embodiment of the invention;

FIGS. **24**A and **24**B are diagrams showing the middle of the production procedure of the photoelectric converting film stack type solid-state image pickup device of the third embodiment;

FIGS. **25**A and **25**B are diagrams showing the production procedure subsequent to FIGS. **24**A and **24**B; and

FIGS. **26**A and **26**B are diagrams showing the production procedure subsequent to FIGS. **25**A and **25**B.

## DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, embodiments of the invention will be described with reference to the accompanying drawings.

### First Embodiment

FIG. **1** is a surface diagram of a photoelectric converting film stack type solid-state image pickup device of a first embodiment of the invention. In the photoelectric converting film stack type solid-state image pickup device **100**, many light receiving portions (pixels) **101** are arranged, in this example, vertically and horizontally or in a lattice manner.

On the surface of a semiconductor substrate which is disposed below the light receiving portions **101** of the photoelectric converting film stack type solid-state image pickup device **100**, three vertical transfer paths (column CCD registers) **102***b*, **102***g*, **102***r* (the suffixes b, g, r correspond to blue (B), green (G), and red (R), respectively, and the same shall apply hereinafter) are formed in correspondence with the light receiving portions **101** which are arranged in the column direction, respectively. A horizontal transfer path (row CCD register) **103** is formed in a lower side edge of the semiconductor substrate.

An amplifier **104** is disposed in an exit portion of the horizontal transfer path **103**. Signal charges detected in the light receiving portions **101** are first transferred to the horizontal transfer path **103** through the vertical transfer paths **102***b*, **102***g*, **102***r*, and then transferred to the amplifier **104** through the horizontal transfer path **103** to be output as an output signal **105** from the amplifier **104**.

On the surface of the semiconductor substrate, electrode terminals **106**, **107**, **108**, **109** connected to four-phase transfer electrodes which are superimposed on the vertical transfer paths **102***b*, **102***g*, **102***r*, and which are not shown are disposed. Four-phase transfer pulses are applied to the electrode terminals. Furthermore, an electrode terminal **110** which is to be connected to a common electrode film that will be described later, and two-phase transfer electrode terminals **111**, **112** for the horizontal transfer path **103** are disposed on the surface.

FIG. **2**A is an enlarged diagram of the inside of the rectangular frame II in FIG. **1**, and shows-light receiving portions **101** for nine pixels, and a longitudinal line **119** for the common electrode film to which the electrode terminal **110** is connected. In FIG. **2**A, the vertical transfer paths **102***r*, **102***g*, **102***b* shown FIG. **1** are omitted.

Each of the light receiving portions **101** is defined by a rectangular pixel electrode film **120**. In the pixel electrode film **120** shown in FIG. **2**A, three pixel electrode films **120***r*, **120***g*, **120***b* are aligned in the light incidence direction via photoelectric converting films described later, and the like as shown in FIG. **2**B.

In the red pixel electrode film **120***r*, a longitudinal line connecting pad **117***r* protrudes in the same plane as the pixel electrode film **120***r*. Similarly, a longitudinal line connecting pad **117***g* protrudes from the green pixel electrode film **120***g*, and a longitudinal line connecting pad **117***b* from the blue pixel electrode film **120***b*. As shown in FIG. **2**A, the pads **117***r*, **117***g*, **117***b* of the same-pixel (light receiving portion) **101** protrude so as to positionally shift from each other.

The reference numeral **122** shown in FIG. **2**A denotes a common electrode film. In the embodiment, also the common electrode film **122** is configured by stacking a red common electrode film **122***r*, a green common electrode film **122***g*, and a blue common electrode film **122***b* via the photoelectric converting films, etc. as described later.

FIG. **3** is a cross-sectional diagram taken along the line III-III in FIG. **2**A showing a section of the portion of the pads **117***r*, **117***g*, **117***b*, and FIG. **4** is a cross-sectional diagram taken along the line IV-IV in FIG. **2**A showing a section of a middle portion of a pixel.

A P-well layer **131** is formed in a surface portion of an n-type semiconductor substrate **130**. In a surface portion of the P-well layer **131**, charge accumulating portions **138***r*, **138***g*, **138***b* configured by an n-type region, and the vertical transfer paths (n-type semiconductor layers) **102***r*, **102***g*, **102***b* defined by channel stops **115** are formed. Longitudinal line connecting portions **137***r*, **137***g*, **137***b* configured by an $n^+$ region are formed in middle portions of the charge accumulating portions **138***r*, **138***g*, **138***b*.

A gate insulating film **132** is formed on the surface of the semiconductor substrate **130**, a transfer electrode **139** made of polysilicon is formed on the film, and an insulating film **134** is formed on the electrode. A light shielding film **133** is formed in the insulating film **134** so that incident light does not enter the vertical transfer paths.

A conductive film is formed on the insulating film **134**, and patterned to form lateral lines **124***r*, **124***g*, **124***b* shown in FIG. **3**. The longitudinal line connecting portions **137***r*, **137***g*, **137***b* of the charge accumulating portions **138***r*, **138***g*, **138***b* are connected to the lateral lines **124***r*, **124***g*, **124***b* through first longitudinal lines **126***r*, **126***g*, **126***b*, respectively.

An insulating layer **125** is formed on a layer in which the lateral lines **124***r*, **124***g*, **124***b* are disposed, and a transparent conductive film is stacked on the layer. The conductive film is patterned to form the pixel electrode film **120***r* which is partitioned for each of the light receiving portions **101**. As a result of this patterning, the pad **117***r* shown in FIG. 2B is formed, and conductive films **116***b*, **116***g* which are aligned with the pads **117***b*, **117***g* in the light incidence direction, and which are separated from other components are left.

A photoelectric converting film **121***r* for detecting red (R) is stacked on the pixel electrode film **120***r*, the pad **117***r*, and the conductive films **116***b*, **116***g*. The photoelectric converting film **121***r* is not required to be partitioned for each of the light receiving portions **101**, and is stacked as a single film over the whole light receiving face which is a collection of the light receiving portions **101**.

On the photoelectric converting film **121***r*, a common electrode film (opposed to the pixel electrode film, and hence referred to also as "opposed electrode film") **122***r* which is common to the light receiving portions **101** for detecting a red signal is stacked similarly as a single film. A transparent insulating film **127** is stacked on the photoelectric converting film.

A transparent conductive film is stacked on the insulating film **127**. The conductive film is patterned, and, in the same manner as described above, the pixel electrode film **120***g* and the pad **117***g* which are partitioned for each of the light receiving portions **101**, and a conductive film **118***b* which is separated from other components, and which is aligned with the pad **117***b* shown in FIG. **2**B are formed. On the pixel electrode film **120***g*, and the like, a photoelectric converting film **121***g* for detecting green (G) is stacked as a single film in the same manner as described above. A common electrode film **122***g* is stacked on the photoelectric converting film, and a transparent insulating film **128** is stacked on the common electrode film.

A transparent conductive film is stacked on the insulating film **128**, and patterned to form a pixel electrode film **120***b* and the pad **117***b* which are partitioned for each of the light receiving portions **101**. On the above, a photoelectric converting film **121***b* for detecting blue (B) is stacked as a single film in the same manner as described above. A common electrode film **122***b* is stacked on the photoelectric converting film, and a transparent protective film **129** is stacked as an uppermost layer.

The lateral line **124***b* is connected to the pad **117***b* of the blue pixel electrode film **120***b* through a second longitudinal line **114***b*, the lateral line **124***g* is connected to the pad **117***g* of the green pixel electrode film **120***g* through a second longitudinal line **114***g*, and the lateral line **124***r* is connected to the pad **117***r* of the red pixel electrode film **120***r* through a second longitudinal line **114***r*. The longitudinal lines **114***r*, **114***g*, **114***b*, **126***r*, **126***g*, **126***b* are produced so as to be electrically insulted from the other components except the pads of the corresponding pixel electrode films, the conductive films **116***g*, **116***b*, **118***b*, and the lateral lines, as described in detail later.

FIG. **5** is a cross-sectional diagram taken along the line V-V in FIG. **2**A showing the connection configuration of the electrode terminal **110** which is shown in FIG. **1**, and the common electrode films **122***b*, **122***g*, **122***r*. A heavily doped P layer **141** is formed in the P-well layer **131** formed in the surface portion of the n-type semiconductor substrate **130**, and a field region (insulating film) **142** is formed on the P layer.

The heavily doped P layer **141** may be formed in the same step as the channel stops **115** shown in FIGS. **3** and **4**, or in another step. The insulating film **142** is formed simultaneously with the formation of the gate insulating film **132** shown in FIGS. **3** and **4**, and the insulating film forming step is continued even after the formation of the gate insulating film **132** to make the film thickness thicker than the gate insulating film **132**.

The insulating film **134** which is identical with that shown in FIGS. **3** and **4** is formed on the insulating film **142**, and a conductive film **124***k* is stacked on the insulating film. The conductive film **124***k* is formed by patterning the conductive film for forming the lateral lines **124***r*, **124***g*, **124***b* shown in FIGS. **3** and **4**. The electrode terminal **110** shown in FIG. **1** is connected to the conductive film **124***k*.

By patterning the conductive film forming the pixel electrode film **120r**, a conductive film **120k-1** is formed, and a longitudinal line **143-1** is formed between the conductive film **124k** and the conductive film **120k-1**.

Similarly, by patterning the conductive film forming the pixel electrode film **120g**, a conductive film **120k-2** is formed, a longitudinal line **143-2** is formed between the common electrode film **122r** and the conductive film **120k-2**, and a longitudinal line **143-3** is formed between the conductive film **120k-2** and the conductive film **120k-1**. Therefore, the common electrode film **122r** and the conductive film **124k** are electrically connected to each other, and the common electrode film **122r** is connected to the electrode terminal **110**.

Similarly, by patterning the conductive film forming the pixel electrode film **120b**, a conductive film **120k-3** is formed, a longitudinal line **143-4** is formed between the common electrode film **122g** and the conductive film **120k-3**, and a longitudinal line **143-5** is formed between the conductive film **120k-3** and the conductive film **120k-2**. Therefore, the common electrode film **122g** and the conductive film **124k** are electrically connected to each other, and the common electrode film **122g** is connected to the electrode terminal **110**.

A transparent conductive film **144** is stacked on a corner of the upper face of the protective film **129**, a longitudinal line **143-6** is formed between the common electrode film **122b** and the conductive film **144**, and a longitudinal line **143-7** is formed between the conductive film **144** and the conductive film **120k-3**. Therefore, the common electrode film **122b** and the conductive film **124k** are electrically connected to each other, and the common electrode film **122b** is connected to the electrode terminal **110**.

As the homogeneous and transparent electrode films **122r**, **122g**, **122b**, **120r**, **120g**, **120b**, thin films of tin oxide ($SnO_2$), titanium oxide ($TiO_2$), indium oxide ($InO_2$), or indium tin oxide (ITO) are used. However, the materials of the films are not restricted to these oxides.

The photoelectric converting films **121r**, **121g**, **121b** may be formed by a single-layer film or a multilayer film. As the materials of the films, useful are various materials such as: silicon, a compound semiconductor, and a like inorganic material; an organic material including an organic semiconductor and organic pigment; and a quantum dot deposition film configured by nanoparticles.

When light from an object is incident on the thus configured photoelectric converting film stack type solid-state image pickup device **100**, photo-charges corresponding to the amount of blue light of the incident light are generated in the blue photoelectric converting film **121b**, and the photo-charges are accumulated in the charge accumulating portion **138b** through the longitudinal line **114b**, the lateral line **124b**, and the longitudinal line **126b**. Similarly, photo-charges corresponding to the amount of green incident light are accumulated in the charge accumulating portion **138g**, and photo-charges corresponding to the amount of red incident light are accumulated in the charge accumulating portion **138r**. The charges (signal charges) accumulated in the charge accumulating portions **138r**, **138g**, **138b** are read out to the vertical transfer paths **102r**, **102g**, **102b** and transferred to the horizontal transfer path **103**. Then, the charges are transferred through the horizontal transfer path **103** to be output from the photoelectric converting film stack type solid-state image pickup device **100**.

FIGS. **6**A and **6**B to **20**A and **20**B show the production procedure of the photoelectric converting film stack type solid-state image pickup device of the first embodiment of the invention shown in FIGS. **3** to **5**. In the figures, "A" is a cross-sectional diagram taken at the same position as FIG. **3**, and "B" is a cross-sectional diagram taken at the same position as FIG. **5**. FIG. **20**A showing the completion of production is identical with FIG. **3**, and FIG. **20**B is identical with FIG. **5**.

The state of FIGS. **6**A and **6**B is produced by the same semiconductor production procedure as the related-art CCD type or CMOS type solid-state image pickup device. Namely, the charge accumulating portions **138r**, **138g**, **138b**, and the vertical transfer paths **102r**, **102g**, **102b** are formed in the P-well layer **131** of the semiconductor substrate **130**, and the insulating film **134** is formed in the surface portion. Openings for the first longitudinal lines **126r**, **126g**, **126b** are formed in the insulating film **134** by etching. Thereafter, the openings are filled with a metal such as tungsten or copper, or conductive polysilicon to form the first longitudinal lines **126r**, **126g**, **126b**. A transparent conductive film is formed on the surface portion, and then patterned, whereby the lateral lines **124r**, **124g**, **124b** and the conductive film **124k** are formed. For example, the patterning process is performed in the sequence of application of resist, exposure, developing, and etching.

Next, as shown in FIGS. **7**A and **7**B, the insulating film **125** is stacked on the surface portion, and, as shown in FIGS. **8**A and **8**B, openings **150r**, **150g**, **150b**, **150k** which reach the lateral lines **124r**, **124g**, **124b** and the conductive film **124k**, respectively are formed by etching. Then, as shown in FIGS. **9**A and **9**B, the openings **150r**, **150g**, **150b**, **150k** are filled with a transparent conductive material to form parts of the longitudinal lines **114r**, **114g**, **114b**, and the longitudinal line **143-1** described with reference FIGS. **6**A and **6**B. Furthermore, as shown in FIGS. **10**A and **10**B, a transparent conductive film **151** is formed on the surface portion.

Next, as shown in FIGS. **11**A and **11**B, the conductive film **151** is patterned, whereby the pixel electrode film **120** is formed, and the pad **117r**, and the conductive films **116b**, **116g**, **120k-1** described with reference to FIG. **3** are formed. Thereafter, as shown FIGS. **12**A and **12**B, the red-detection photoelectric converting film **121r** is stacked on the surface portion, and, as shown in FIGS. **13**A and **13**B, the common electrode film **122r** is stacked on the photoelectric converting film **121r**.

Next, as shown in FIGS. **14**A and **14**B, a resist film **152** is formed on the surface, and openings **153b**, **153g** which are aligned with the positions of the conductive films **116r**, **116g** are formed by etching. End portions of the photoelectric converting film **121r** and the common electrode film **122r** which are on the conductive film **120k-1** are shaved off as shown in FIG. **14**B.

As described above, according to the embodiment, in succession to the step of stacking the photoelectric converting film **121r**, the common electrode film **122r** is stacked, and the openings **153b**, **153g** are formed by etching together with the common electrode film **122r** and the photoelectric converting film **121r**. Therefore, the interface between the photoelectric converting film **121r** and the common electrode film **122r** is not damaged, and the number of etching steps for the longitudinal line openings can be reduced. When etching is to be performed, the conductive films **116g**, **116b** are disposed in the bottoms of the openings. Consequently, etching can be accurately stopped at the positions of the conductive films **116g**, **116b**.

After the openings **153b**, **153g** are formed, the insulating film **127** is stacked on the surface portion to fill the openings **153b**, **153g** as shown in FIGS. **15**A and **15**B, and the insulating film **127** is stacked on the shaved portion shown in FIG. **14**B. Next, as shown in FIGS. **16**A and **16**B, openings **154g**, **154b** which are smaller in diameter than the openings **153g**, **153b** are formed by etching, and an opening **154k-i** which

reaches the common electrode film **122***r*, and an opening **154***k*-**2** which reaches the conductive film **120***k*-**1** are opened in the end portion (FIG. **16**B).

Next, as shown in FIGS. **17**A and **17**B, the openings **154***g*, **154***b*, **154***k*-**1**, **154***k*-**2** are filled with a transparent conductive material to form the longitudinal lines **114***g*, **114***b*, **143**-**2**, **143**-**3**. After the openings are filled with the transparent conductive material, the surface is subjected to a smoothing process such as CMP (Chemical Mechanical Polishing).

As described above, in the embodiment, the longitudinal lines **114***g*, **114***b* which pass through the three layers or the insulating layer **127**, the common electrode film **122***r*, and the photoelectric converting film **121***r* are produced in the same step. Therefore, the number of steps of producing the longitudinal lines is reduced.

Then, a procedure which is similar to the production procedure of FIGS. **10**A and **10**B to **17**A and **17**B is repeated to, as shown in FIGS. **18**A and **18**B, form the longitudinal line **114***b* which passes through the green-detection photoelectric converting film **121***g* and the common electrode film **122***g*, and form the longitudinal lines **143**-**4**, **143**-**5** in the end portion.

Furthermore, as shown in FIGS. **19**A and **19**B, the pixel electrode film **120***b* and the pad **117***b* are formed, the blue-detection photoelectric converting film **121***b*, the common electrode film **122***b*, and the transparent protective film **129** are formed thereon, openings are formed by etching at predetermined places of the transparent protective film **129**, and the openings are filled with a conductive material to form the longitudinal lines **143**-**6**, **143**-**7**. Finally, as show in FIGS. **20**A and **20**B, the conductive film **144** which connects the longitudinal lines **143**-**6**, **143**-**7** to each other is formed.

As described above, according to the embodiment, in succession to the step of stacking the lower photoelectric converting film, the stacking of the common electrode film is successively conducted, and the common electrode film and the photoelectric converting film are etched together to form openings. Therefore, the interface between the photoelectric converting film and the common electrode film is not damaged, and the number of etching steps for longitudinal line openings can be reduced. As a result, the performance of photoelectric conversion can be improved, and the production cost can be lowered.

## Second Embodiment

FIGS. **21**A and **21**B are cross-sectional diagrams of a photoelectric converting film stack type solid-state image pickup device of a second embodiment of the invention, and FIGS. **22**A and **22**B are cross-sectional diagrams showing the middle of the production of the device. In the figures, "A" is a cross-sectional diagram taken at the same position as FIG. **3**, and "B" is a cross-sectional diagram taken at the same position as FIG. **5** in the same manner as FIGS. **6**A and **6**B to **20**A and **20**B.

FIGS. **22**A and **22**B are diagrams showing a production procedure after the production step of FIGS. **11**A and **11**B in the first embodiment. In the first embodiment, after the step of FIGS. **11**A and **11**B in which the conductive film **151** is patterned, the photoelectric converting film **121***r* is stacked as shown in FIGS. **12**A and **12**B. When the conductive film **151** is patterned to form the conductive films **116***g*, **116***b*, the pad **117***b* and the pixel electrode film **120***b*, a step difference is formed in an end of each film.

When the conductive film **151** is thin, these step differences produce no problem. When the thickness is not negligible, asperities corresponding to the step differences of the ends of the films **116***g*, **116***b*, the pad **117***b*, and the pixel electrode film **120***b* are formed on the surface of the photoelectric converting film **121***r* stacked on the conductive film, thereby producing a possibility that the dark current (leakage current) may be increased, or pixel defects or the like may be caused. From the viewpoint that the sheet resistance is reduced, it is preferable to thicken the pixel electrode film **120***b*. When the film is excessively thick, however, the step differences are large.

In the embodiment, after the films **116***g*, **116***b*, the pad **117***b*, and the pixel electrode film **120***b* are patterned, therefore, spaces between the films are filled with a transparent insulating film **160**, and the surface is subjected to a smoothing process. This is applied also to the step differences of the electrode films in the upper layers or the green- and blue-detection photoelectric converting films **121***g*, **121***b* (see FIGS. **21**A and **21**B), and spaces are filled with the transparent insulating film **160**. As a result, asperities of the photoelectric converting films can be eliminated, and the performance of photoelectric conversion can be further improved.

## Third Embodiment

FIGS. **23**A and **23**B are cross-sectional diagrams of a photoelectric converting film stack type solid-state image pickup device of a third embodiment of the invention, and FIGS. **24**A and **24**B to **26**A and **26**B are diagrams showing the middle of the production of the device. In the figures, "A" is a cross-sectional diagram taken at the same position as FIG. **3**, and "B" is a cross-sectional diagram taken at the same position as FIG. **5** in the same manner as FIGS. **6**A and **6**B to **20**A and **20**B.

In the first and second embodiments, as shown in, for example, FIG. **5**, the longitudinal line **143**-**2** is connected to the longitudinal line **143**-**3** through the conductive film **120***k*-**2**. The conductive film **120***k*-**2** is formed by patterning the conductive film for forming the pixel electrode film **120***g*. As described in the second embodiment, preferably, the pixel electrode film is thin because asperities of the photoelectric converting film are suppressed. When the pixel electrode film is thin, however, also the conductive film **120***k*-**2** which is formed by the same patterning process is thin, and the connection resistance between the longitudinal lines **143**-**2** and **143**-**3** is increased.

In the embodiment, after the insulating film **127** shown FIGS. **15**A and **15**B is stacked, a recess **170** is shaved off at a place aligned with the conductive film **120***k*-**2** (see FIGS. **18**A and **18**B) which is stacked above the film, as shown in FIG. **24**B. According to the configuration, as shown in FIGS. **25**A and **25**B, the openings **154***b*, **154***g*, **154***k*-**1**, **154***k*-**2** are opened in the same manner as FIGS. **16**A and **16**B, and thereafter the openings **154***b*, **154***b*, **154***k*-**1**, **154***k*-**2** are filled by stacking a conductive material as shown in FIGS. **26**A and **26**B. At this time, also the recess **170** is filled with the conductive material, and a bridge portion **171***r* connecting the longitudinal lines **143**-**2** and **143**-**3** to each other is formed. When the conductive film **120***k*-**2** is formed on the bridge portion **171***r*, therefore, the connection resistance between the longitudinal lines **143**-**2** and **143**-**3** is lowered.

As shown in FIGS. **23**A and **23**B, in the embodiment, the conductive film **144** shown in FIG. **5** is not disposed on the uppermost protective film **129**. When the connection resistance of a bridge portion **171***b* for the uppermost layer is low, it is not required to dispose the conductive film **144**, and the uppermost face can be made flat. Alternatively, the conductive film **144** may be disposed. When the resistances of the

bridge portions **171**_r_, **171**_g_ are low, the conductive films **120**_k_-**2**, **120**_k_-**3** may be omitted.

In the embodiments described above, a CCD type signal read circuit is formed on a semiconductor substrate. The invention can be similarly applied to a photoelectric converting film stack type solid-state image pickup device in which a signal read circuit is configured by a MOS transistor circuit. The embodiments in which the connection pads **117**_r_, **117**_g_, **117**_b_ outward protrude from the peripheries of the pixel electrode films **120**_r_, **120**_g_, **120**_b_ have been described. Alternatively, the invention can be applied also to a configuration where longitudinal lines are connected to the inner side of the pixel electrode film **120**.

In the embodiments, after, for example, an insulating film is formed, a resist film is formed, and openings for longitudinal lines are formed by etching. Alternatively, a transparent resist film may be used as the insulating films **125**, **127**, **128**, etc. This configuration is effective in the case where the etching selectivity of a resist film and an insulating film is not large.

In the embodiments, the solid-state image pickup devices in which three photoelectric converting films for detecting three colors or red, green, and blue are stacked have been described. The invention is applicable to a solid-state image pickup device in which at least two photoelectric converting films are stacked.

According to the invention, the number of steps of producing longitudinal lines for connecting pixel electrode films to a signal read circuit can be reduced, the production cost can be lowered, and the performance of photoelectric conversion can be improved.

The photoelectric converting film stack type solid-state image pickup device of the invention can be used in place of the related-art CCD or CMOS image sensor. When three photoelectric converting films are disposed, signals of three colors or red, green, and blue can be obtained without using color filters. Therefore, the device is useful when it is mounted on a digital camera.

The entire disclosure of each and every foreign patent application from which the benefit of foreign priority has been claimed in the present application is incorporated herein by reference, as if fully set forth.

What is claimed is:

**1**. A photoelectric converting film stack type solid-state image pickup device comprising:

a semiconductor substrate in which a signal read circuit is formed;

a plurality of photoelectric converting films stacked alternately with insulating layers, the photoelectric converting films being above the semiconductor substrate, in which each of the photoelectric converting films is sandwiched between a pixel electrode film patterned for each pixel and an opposing electrode film opposed to the pixel electrode film; and

a smoothing transparent insulating film on a portion where a conductive film is removed away by patterning the pixel electrode film,

wherein the pixel electrode film of an upper one of the photoelectric converting films is connected to the signal read circuit by a first longitudinal line passing through a lower one of the photoelectric converting films, and

wherein, in the first longitudinal line, a passing portion which passes through the lower photoelectric converting film is formed by filling an opening with a conductive material, the opening being from a plane of the pixel electrode film stacked below the lower photoelectric converting film to an upper end face of the insulating layer stacked above the lower photoelectric converting film.

**2**. The photoelectric converting film stack type solid-state image pickup device according to claim **1**, further comprising:

a first conductive film which is patterned simultaneously with patterning of the lower pixel electrode film, the first conductive film being at a portion of the same plane with which the passing portion is in contact; and

a second conductive film which is patterned simultaneously with patterning of the upper pixel electrode film, the second conductive film being on the upper end face of the insulating layer with which the passing portion is in contact.

**3**. The photoelectric converting film stack type solid-state image pickup device according to claim **1**, wherein

the plurality of photoelectric converting films comprises:

a red-detection photoelectric converting film having a peak in a red spectral sensitivity characteristic;

a green-detection photoelectric converting film having a peak in a green spectral sensitivity characteristic; and

a blue-detection photoelectric converting film having a peak in a blue spectral sensitivity characteristic.

**4**. The photoelectric converting film stack type solid-state image pickup device according to claim **1**, further comprising:

a second longitudinal line for the opposing electrode film, the second longitudinal line upstanding at a place which is an end portion of said photoelectric converting film, and at a place which is separate from the photoelectric converting film;

a third longitudinal line for the opposing electrode film, the third longitudinal line being disposed for each of the opposing electrode films, and extending from an upper end face of the insulating layer stacked on the opposing electrode film of each of the photoelectric converting films, to the opposing electrode film; and

a connecting conductive film which electrically connects, on upper end faces of the insulating layer, the second longitudinal line with the third longitudinal line.

**5**. The photoelectric converting film stack type solid-state image pickup device according to claim **4**,

wherein those other than an uppermost one of the connecting conductive films are formed simultaneously with patterning of a conductive film formed on the upper end face of the insulating layer to form the pixel electrode film.

**6**. The photoelectric converting film stack type solid-state image pickup device according to claim **4**,

wherein a recess is disposed in the upper end face of the insulating layer between the third longitudinal line and the second longitudinal line, and the recess is filled with a conductive material which is identical with the third longitudinal line and the second longitudinal line, wherein the third longitudinal line and the second longitudinal line are electrically connected to each other.

**7**. The photoelectric converting film stack type solid-state image pickup device according to claim **4**,

wherein the third longitudinal line for the opposing electrode film and the second longitudinal line for the opposing electrode film are formed in a same production step as the first longitudinal line which connects the pixel electrode film to the signal read circuit.

* * * * *